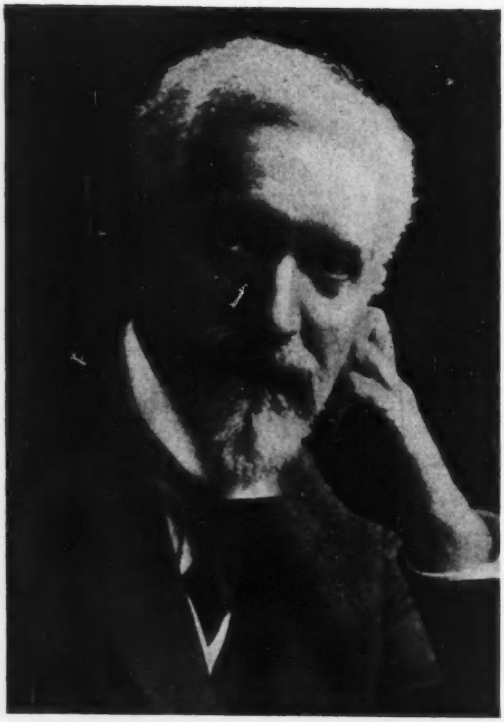
OBITUARIES

During the past three years death has come to three of the principal persons concerned with the origin and development of the Biological Board of Canada. Also there has occurred the first death in the Board's service of an investigator when actively engaged in his work.



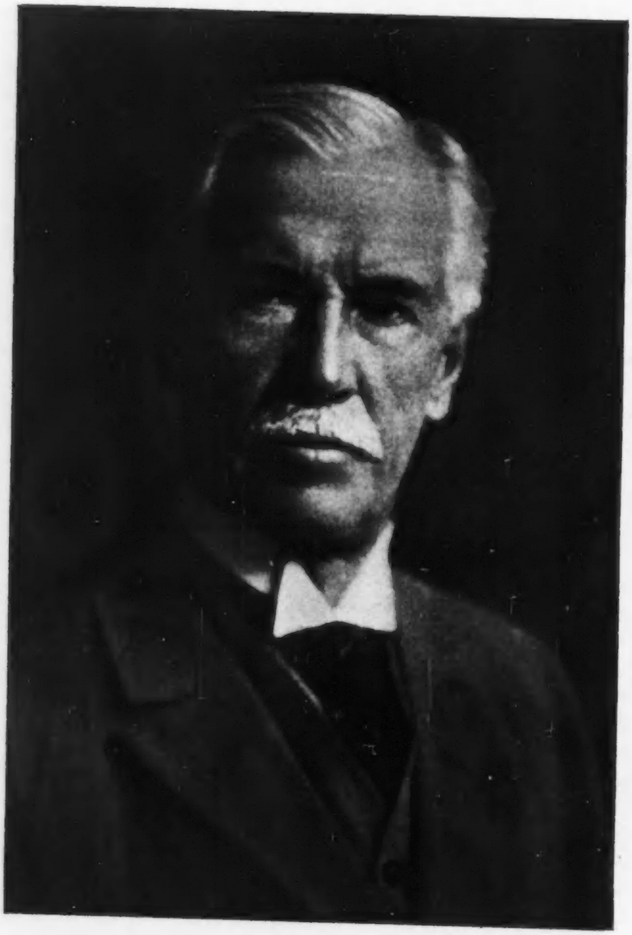
PROFESSOR A. B. MACALLUM, M.A., PH.D.,
LL.D., D.SC., F.R.S.C., F.R.S.,
1858-1934.

Professor A. B. Macallum, who died at his home in London, Ont., on April 6, 1934, was an outstanding personality in the development of the Biological Board.

He was associated almost from its beginning with the movement for the scientific investigation of the Canadian fisheries as a member of the Canadian committee appointed in 1897 by the British Association for the Advancement of Science on the recommendation of a committee of Section D that held a sitting at the Toronto meeting of the Association in 1896. Later when the Canadian committee secured the establishment of a Marine Biological Station he was included in the membership of the Board of Management, which later became the Biological Board of Canada. On the death of Professor D. P. Penhallow in 1910, he was appointed its Secretary. This office he held until his resignation from the Board in 1920, after ten years of valuable service. His foresight, energy and perseverance were largely responsible for the extension of the energies of the Board, for the determination of its policies and for the recognition of its autonomy, for which he strove to the end.

He not only gave the Board the benefit of his executive abilities, but also served as one of the investigators at the St. Andrews Station, carrying on important studies of the salt content of the blood of various animals. After retirement from the Board he was appointed Chairman of the National Research Council, and in that position was able to co-operate to some extent in the activities of the Board.

At an early stage in his career he was associated with Professor R. Ramsay Wright in a classical study of the anatomy of the cat-fish, ***Ameiurus***, the results of which were published in 1884, and his fundamental work in physiology and biochemistry repeatedly brought him into touch with life in the waters, as in his comparison of the salt content of vertebrate blood with that of sea water. He upheld the ideal of accurate and thoroughly scientific work. It may be truly said that after the retirement of Professor Wright, the Vice-Chairman, Professor Macallum was the mainstay of the Board's activities.



PROFESSOR A. P. KNIGHT, M.A., LL.D., M.D., F.R.S.C.,
1849-1935.

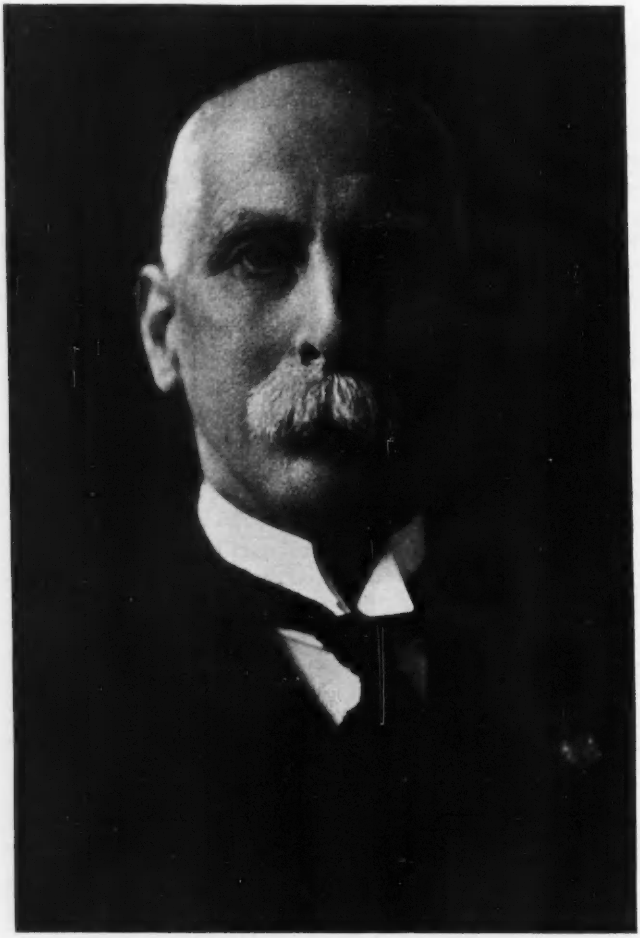
Professor A. P. Knight, whose death occurred at Kingston, Ontario, on October 18, 1935, was most noteworthy as one who, on retirement from active life in Queen's University, devoted most of his energies for many years to public service in the work of the Biological Board. With a keen desire for practical results and ability for clear and forceful presentation of any case, of which he was the advocate, he became the leader in every movement for bettering fishery practice.

He is to be credited with taking the first formal steps toward the establishment of a laboratory for fishery investigation, which led to the formation of the Biological Board. In 1895 he wrote the Secretary of the Royal Society of Canada, urging such a course and his letter was published in the Society's Proceedings. He was made a member of the Board of Management of the first Biological Station, for which the Government of Canada made provision in 1898, and continued to take an active part in the direction of the work till his definite retirement in 1925 at the age of seventy-six. His interest in the work continued throughout the remaining ten years of his life.

From the first he was active in direct attacks on practical problems, the very first of the papers published by the Board on the results of investigations being by him on "The effects of polluted waters on fish-life" in *Contributions to Canadian Biology*, **1901**. Papers followed on the effects of dynamite explosions and sawdust upon fish life and on fishery bait experiments.

His most extensive work was in connection with the lobster fishery. He made a very thorough attempt to obtain success in the rearing of lobster larvae, and demonstrated the ineffectiveness of the system of lobster hatching, which had been in vogue for many years, and which was thereupon abandoned. He then undertook an educational campaign for the adoption of better measures of conservation. He also attempted to improve the conditions in the canning of lobsters, particularly by introducing a system for the inspection and grading of lobster factories. His final work consisted of attempts to ascertain the effectiveness of fish cultural methods for trout and salmon.

As Chairman of the Board from 1920 to 1925, he guided its development as it approached the time of reorganization to permit effective attack on the problems involved in industrial procedures, such as canning, smoking and freezing.



PROFESSOR E. E. PRINCE, B.A., LL.D., F.L.S., F.R.S.C.,
1858-1936.

During the first year after assuming his life work on April 1, 1893, as Dominion Commissioner of Fisheries for Canada, Professor Edward E. Prince prepared for the Minister of Marine and Fisheries a report on "A marine scientific station for Canada", for which his previous experience in Great Britain well fitted him. In this report he visualized the varied activities that in the course of the years since that time have developed first at the Biological Stations and later at the Experimental Stations of the Biological Board.

He was made Chairman of the committee of the British Association for the Advancement of Science that prepared and presented a memorial to the Canadian Government in 1898. This memorial urged the provision of funds for the construction and maintenance of a Canadian Biological Station, and he became Director of the Station which eventuated and had its first season of operation in 1899. The Board of Management of this Station developed into the Biological Board of Canada, of which he was Chairman from the beginning. He continued as the head of this body, that has developed fishery research in Canada, until 1921 when he took the office of Secretary, remaining in the latter position until his retirement from active life in 1924 at the age of sixty-six years. He remained a member of the Biological Board until his death on October 10, 1936.

With the background of original investigations on the life histories of various fishes in the waters around Great Britain, an extensive knowledge of the fisheries in all parts of Canada, and a wide acquaintance with men prominent in the scientific world, Professor Prince was admirably adapted to guide the development of research in connection with Canada's fisheries. His genial personality and keen interest in individuals and all human activities were similarly valuable in securing the co-operation of volunteer investigators from the various Canadian universities. While for some time he continued his own investigations, he is chiefly to be remembered for the stimulus he gave to work in the most varied directions as a result of his very wide experience and knowledge of interesting phenomena.

John Alexander Stevenson, M.A., 1910-1936.

Mr. Stevenson was born at Devonport, England, on September 28, 1910. His early education was obtained at St. Christopher's, Eastbourne, at Berkhamstead School and Scarborough College. He developed an early interest in the sea and contributed notes to the Scarborough Natural History Society, on collections made along that coast.

Coming to Canada in 1929 he entered Queen's University, receiving an Honour Bachelor's degree in 1934. The following winter was spent at the University of Western Ontario, where he held a Demonstratorship and obtained a Master of Arts degree. During 1935-36 he was registered at the University of Toronto for a Doctor of Philosophy degree.

His interest in marine life led him to come to the Atlantic Biological Station at St. Andrews, N.B., during the summer of 1931 when he was employed as a museum assistant. Since then each summer has seen him associated with the Station's work. From an investigation of laboratory problems on the reproduction and growth of the scallop he became fitted to undertake at Digby, N.S., during the summers of 1935 and 1936, a field study of the scallop on the important fishing area there.

His accidental death by drowning in the Annapolis basin on September 15, 1936, while engaged in his work, removed a promising young biologist whose interests, ability and methodical temperament bid fair to have carried him far.

The Biology of the Zooplankton Population in the Bay of Fundy and Gulf of Maine with Special Reference to Production and Distribution.

By Charles J. Fish, *Rhode Island State College*

and

Martin W. Johnson, *Scripps Institution of Oceanography*

(*Contribution No. 135 of the Woods Hole Oceanographic Institution*)

(*Received for publication March 4, 1937*)

ABSTRACT

Analyses in the gulf of Maine and bay of Fundy show the zooplankton population to be dominated by a relatively few species of boreal endemic crustaceans. *Calanus finmarchicus*, the most abundant form, averaged 39.9 per cent by number in the total region during the period, April to September in 1932, and 35.5 per cent for the year in the bay of Fundy. Fluctuations in the volume of zooplankton reflect to a large extent numerical changes in the stock of this species. The vernal rise in 1932 occurred following propagation of *Calanus*, and the rapid downward trend in June coincided with the critical period of maturation and subsequent mortality of adults after spawning.

Due to differences in the time of spawning in different parts of the region, two, and in some cases three, breeding stocks of boreal plankton animals can usually be distinguished. The distinct spawning periods are continued in subsequent generations that year no matter where distributed.

Productivity was found to be closely correlated with temperature and stability of the water mass, and dispersal with the nontidal circulation in the region. The vernal crop of boreal plankton species appears to be derived largely from adults maturing in the western or outer gulf. With the advance of the season the centre of production moves to the eastern basin. The turbulent New Brunswick-eastern Maine coastal zone as far west as Mount Desert is relatively unproductive, and characterized by small zooplankton volumes.

CONTENTS

PREFACE

The present report on an investigation covering the period July 28, 1931 to September 29, 1932 forms part of the program of the International Passamaquoddy Fisheries Commission. This paper has been prepared by the senior author, who assumes responsibility for the opinions and conclusions presented. The junior author rendered valuable assistance in field work and laboratory analyses during the investigations of the second year. Reports have already appeared on phytoplankton by Dr. H. H. Gran and Mr. Trygve Braarud (1935), herring by Mr. Michael Graham (1936), hydrography by Dr. E. E. Watson (1936) and the biologies of three species of copepods, *Calanus finmarchicus, Pseudocalanus minutus,* and *Oithona similis,* by Dr. C. J. Fish (1936a, 1936b, 1936c).

We desire to express thanks to Dr. A. G. Huntsman and Dr. H. B. Bigelow for many helpful suggestions and the facilities of the Atlantic Biological Station and the Woods Hole Oceanographic Institution. Acknowledgment is also made to our above mentioned colleagues, for generous co-operation at all times, to Mr. W. Herrington, Mr. H. B. Hachey, Dr. A. H. Leim and Mr. O. E. Sette for valuable material and information, and to Miss H. E. Rigby, clerk, for assistance in computing results.

INTRODUCTION

The problem confronting the Commission has been to determine to what extent the fishery of the Quoddy region would be affected, favourably or unfavourably, by the construction of a series of hydroelectric power dams in the entering passages to Passamaquoddy bay, situated on the boundary between Maine and New Brunswick. The zooplankton aspect of this problem is concerned with the influence of the mixing mechanism in the passages on the production and availability of food for plankton-feeding fishes, particularly of the herring which forms the most important commercial species in the region.

A theory had previously been advanced (Huntsman 1928, p. 34) that the thorough tidal mixing of the water mass results in an indraft of deep water, rich in plankton animals, which provides an abundant supply of available food, and this might account at least in part for the large herring population (Graham 1936, p. 125). Although this condition is attributed only to the zone of mixing, it presupposes an abundant source of zooplankton supply in the deep layers of the immediate area outside of the passages. In addition to the evidence offered by the fishery this viewpoint is supported by large flocks of sea birds which collect in the region of the most violent mixing during the summer, and also by frequent swarms of *Meganyctiphanes norvegica* observed commonly here and rarely elsewhere at the surface.

Contrasted with these indications of an abundant zooplankton supply are records of consistently scanty hauls made by previous investigators in this area (Bigelow 1914a, pp. 34, 104 and 130; 1926, pp. 83-85), and evidence that propagation of some of the important species of the year-round population is largely

unsuccessful in the bay of Fundy (Huntsman 1918, p. 65; Huntsman and Reid 1921, p. 110; Wright 1929; Battle 1930).

It had further been suggested that the influence of Quoddy mixing is not purely local, but through the agency of ocean circulation nutrient salts are transported out of the region. Mixed water leaving the Quoddy region would be expected to move out of the bay of Fundy along the east side of Grand Manan and thence in part to the coast of Maine, to supplement the results of local mixing (Huntsman 1928, p. 35).

The problem therefore necessitated a consideration of the zooplankton population of the general region which might serve as a source of supply for the Quoddy area or be influenced by outwash from it. Essentials to be determined were: (1) the quantity of zooplankton, (2) its composition, (3) source and dispersal, (4) the extent to which the stock in the bay of Fundy (including Passamaquoddy bay) is recruited from breeding areas within and beyond the influence of Quoddy mixing, and (5) possible correlation of zooplankton with herring concentration in the Quoddy region.

Program and Observations

Field operations

Field work began on July 28, 1931, and during the first summer was confined to local studies in the Quoddy area, with the exception of one cruise (no. 4) along the coast of Maine as far west as Casco bay on August 21 to 26, and another (no. 5) in the bay of Fundy as far east as cape Spencer on September 1 to 5 (fig. 1).

Throughout the autumn and winter of 1931-32, four stations (sta. 1C, 5, 6, and 8A) were taken at regular intervals to indicate seasonal changes in the zooplankton of Passamaquoddy bay, the Outer Quoddy region, and two offshore localities in the bay of Fundy (cruises 6-25). These routine observations were supplemented during December and January by 49 Petersen trawl samples taken in the course of herring investigations by Mr. M. Graham over a wide area in the bay of Fundy and extending south of cape Sable. Although highly selective and not comparable with metre net collections for quantitative studies, they indicate the distribution of larger members of the zooplankton population, particularly the euphausiids and sagittae. Unfortunately, due to a fire, no data are available for the period between January and March, 1932.

Beginning April 15, 1932, monthly cruises were instituted, covering a series of 28 stations located in eight sections between cape Spencer and Casco bay (fig. 2). These cruises, covering the spring and summer propagation periods, occurred as follows: cruise 26, April 15-May 2; cruise 27, May 19-31; cruise 28, June 20-July 1; cruise 30, August 8-21; cruise 32, September 14-26.

At times during the second season it was possible to enlarge the range of observations through co-operation with vessels operating simultaneously in other parts of the region. In April the zooplankton material was supplemented by a series of half metre net collections from the vicinity of Georges bank (fig. 2, Albatross stations) and a double line of observations (half metre net and Petersen

trawl) along the coast from Passamaquoddy bay to Halifax (Nova series). In May, collections (metre net) were obtained from a line of eight Nova stations between cape Sable and cape Ann and eight stations in the bay of Fundy. In August a series of 16 special stations was made in inland waters extending from Casco bay, Maine, to Maces bay, New Brunswick, with two on the Nova Scotian side in St. Mary bay and Annapolis basin (fig. 2). Eleven special stations (Atlantis series) widely distributed over the gulf of Maine and Georges bank were made in September.

Between the monthly cruises observations were restricted to the Quoddy region, cruise 29 (July 30) comprising stations 1C and 5 (fig. 2), and cruise 31 (September 12-13), a series of simultaneous collections in the Western passage, the Letite passages, and adjacent waters on various phases of the tide for the purpose of determining the extent of zooplankton interchange between Passamaquoddy bay and the Outer Quoddy region.

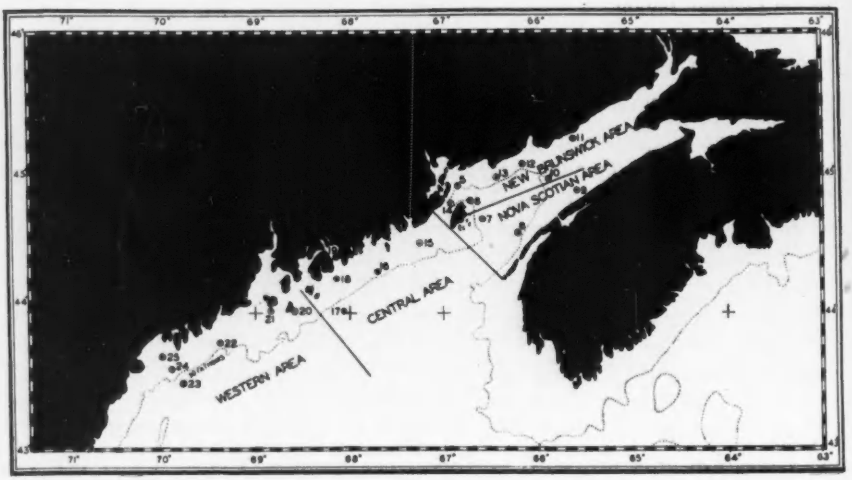


FIGURE 1. Zooplankton stations in 1931.

ZOOPLANKTON MATERIAL

Quantitative and qualitative analyses were made of 434 metre net, 107 half-metre net, 91 Petersen trawl and 174 pump samples. A series of 32 metre net samples taken in 1917 at Prince stations 3 and 5 in the bay of Fundy and station 6 in Passamaquoddy bay were also examined for purposes of comparison.

METHODS

Hydrographic determinations in connection with the zooplankton investigations were made with the same equipment and methods described in the report of the hydrographer (Watson 1936, p. 143).

The zooplankton field work consisted of an investigation of (1) breeding

areas, development and subsequent dispersal of young stages, and (2) quantitative and qualitative distribution (geographical and seasonal) of the adult population. Both of these lines of investigation were carried on simultaneously but with different methods.

For the sampling of eggs and immature stages, the pump was used during the summer months (July-September). A two-inch (ca. 5 cm.) rubber hose with a check valve near the end was attached to the dredging wire and lowered to the proper depths indicated on the metre wheel. With a double action hand pump equipped with a gauge, water was pumped into a plankton net (no. 20 silk) sus-

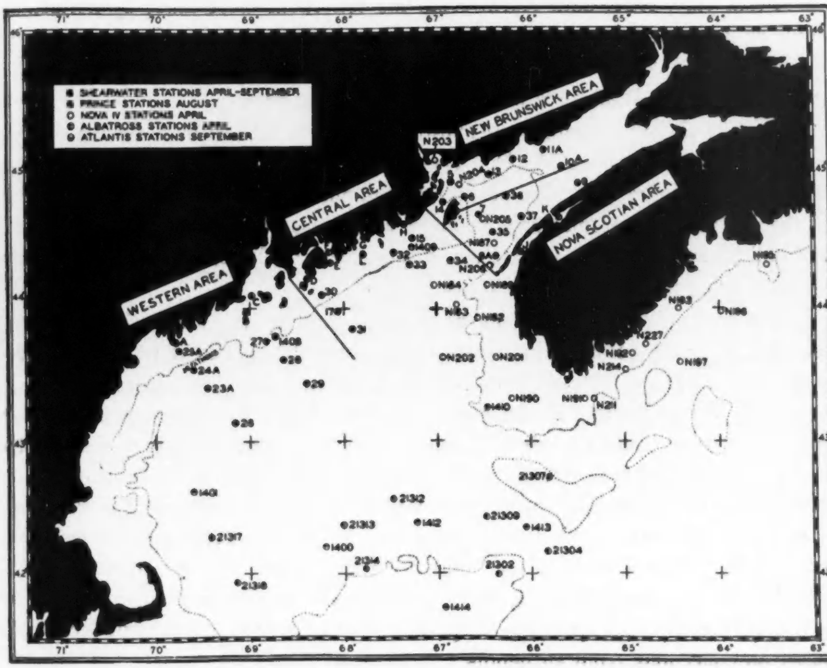


FIGURE 2. Zooplankton stations in 1932.

pended in a cylindrical tank. By raising or lowering the end of an overflow pipe attached near the bottom of the tank, it was possible o maintain the level of the water slightly below the mouth of the net, thus allowing maximum filtering surface without danger of crushing delicate organisms. The sample was removed from a petcock bucket at the cod end of the net, a volume of 250 litres of water from each of four levels, 0, 10, 30, and 50 metres being filtered at each station. Analyses were made by the Sedgewick-Rafter counting method, and the number of individuals per cubic metre calculated. A Stempel pipette was used in removing one cubic centimetre of the sample for counting. In determining horizontal distribution, the value taken for each station represents the mean of the four levels.

Until weather conditions permitted the use of the pump (end of June) half-metre nets (two metres in length) of no. 10 silk were utilized. The hauls were of 15 minutes duration and were oblique from 50 metres to the surface. The counts were made as in the pump samples, except that the number of organisms per minute of towing was taken as the unit of measure.

For adult population studies metre nets of the standard type used by the U.S. Bureau of Fisheries were selected. These were one metre in diameter and four metres long. The first metre, forming the cylindrical section, was of no. 0000XX and the remaining conical portion of no. 0XX bolting silk.

From July, 1931, until April, 1932, the collections were made by horizontal hauls of 20 minute duration at the surface, 50 metres, and as near as possible to the bottom. In depths not exceeding 60 metres only two hauls were made. Sub-surface collections in all cases were made with closing nets.

Oblique closing net hauls were substituted in place of horizontal towing during the second season (cruises 26-32). These consisted of a lower haul from near the bottom to 50 metres where the net was closed, and a second haul from 50 metres to the surface. Horizontal haul volumes were measured by the settling method and oblique hauls by both settling and displacement methods, the time interval of the haul being used as a unit of measure.

The qualitative analyses of metre net collections were made in the following manner: after the volume of the sample had been determined it was thoroughly mixed and a portion removed with a Stempel pipette (2 cc.) and transferred to a petri dish for counting. If the specimens were large, four and sometimes six cubic centimetres were removed. Counting was done with the lowest magnification possible for accurate identification, and varied according to the nature of the sample. In each sample the total number of all species occurring in five fields of the microscope were counted, totalled, and their *relative percentage by number* computed. The remainder of the sample was then examined and any species not included in the counts listed as traces (T). In the present report, unless otherwise stated, the percentage value assigned to each species will represent the mean based on collections from all depths.

Collecting by other vessels was done with equipment supplied by the Commission and with uniform methods. Petersen trawl collections were made in oblique hauls from the bottom to the surface.

To record repeated observations at the same stations, the cruise number was inserted before the station number, the two being separated by a decimal point, as 05.06 indicating cruise 5, station 6. For special stations made possible through co-operation with other investigators, their numerical series have been inserted with the name of the ship. Where changes in the location of regular stations were made, the new position is indicated by the former station number with a letter added, as in the case of sta. 8A. A series of neritic stations in August, 1932, were assigned alphabetical letters.

PHYSICAL OBSERVATIONS

The production, dispersal, and survival of zooplankton populations are more closely correlated with hydrographic conditions than with any other readily detectable controlling factors. Temperature appears to determine largely the type of community which can maintain itself in any particular area, while depth, circulation, turbulence, and, in extreme cases, salinity influence, its horizontal distribution.

In summarizing physical characteristics and seasonal changes in the region, it has been necessary to draw largely upon the results of previous investigators. For a more detailed account of the hydrography of the bay of Fundy during the period of the present investigations see Watson (1936), and for vertical profiles of temperature and salinity correlated with phytoplankton and chemical data, Gran and Braarud (1935). It will be our purpose here to consider only those aspects which appear to be of particular significance in the biology of zooplankton.

Temperature

The gulf of Maine is at the surface an open bay. Between 10 and 50 metres, Georges bank forms an island approximately 100 miles long (at the latter level) across the entrance, and the point of Nova Scotia extends about 40 miles farther west than at the surface. Below the 100 metre level the gulf is an almost enclosed basin with two narrow entering passages.

Separated from the open Atlantic by topographical and hydrographical barriers, temperature variations are for the most part indicative of local response to seasonal changes. External influence, sufficient to affect significantly biological conditions, originates from three principal sources: (1) an inflow of warm (6° to 8°C.) slope water through the eastern channel along the bottom, particularly in the spring, maintains a uniform bottom layer of approximately 5° to 6° in the deeper parts of the gulf throughout the year (winter cooling penetrates to depths of less than 150 metres); (2) an inflow of cold water in the upper 100 metres past cape Sable from the eastward in late March and April is variable, but temporarily retards and may even reverse vernal warming of the surface layer in the northeastern part of the gulf, sometimes lowering it to 0°; (3) an outwash of cold water from the Saint John river with the melting of the ice for a short time exerts a somewhat similar influence over a smaller area in the bay of Fundy, at first retarding vernal warming of the surface stratum and later resulting in a localized band of cold water (4° to 6°) which follows the course of the drift at an intermediate level along the New Brunswick coast and remains against the eastern slope of Grand Manan through the greater part of the summer.

ANNUAL TEMPERATURE CYCLE

The region can be classed as typically boreal, having an average offshore range over the gulf from about 2° to 20°C. and in the bay from 1° to 15°C. The Nova Scotian current may lower temperatures temporarily to 0°C, in the northeastern part of the gulf, and the Saint John outwash to 0°C. or even lower in the bay. A

zooplankton population concentrated by day below 40 metres would, throughout the region, encounter there an annual variation of not more than 10° and in the deeper levels (below 150 metres) probably less than 4°.

In the gulf of Maine autumnal cooling becomes noticeable first in August or early September in the more stratified western and deeper areas where the summer maximum may be passed a month earlier than in the more turbulent region east of Penobscot bay. At depths of 100 metres warming may continue into December. Vernal warming begins at the surface in late February or early March. At this time the water mass is heated both from above and below, the latter due to bottom

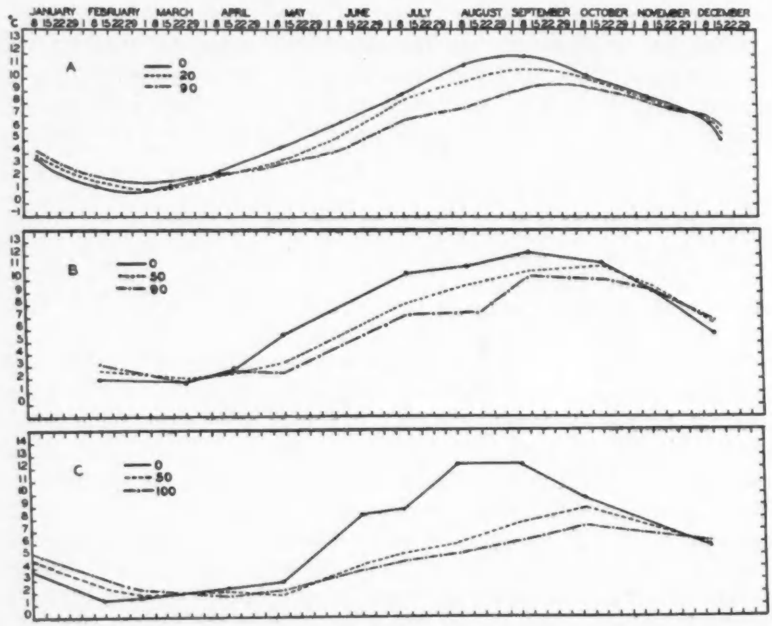


FIGURE 3. Average range of temperature at station 5 during the period 1921-1930 (A), and in 1932 (B); station 6 (Prince sta. 3) in 1917 (C). Monthly readings. Depth in metres.

slope water mixing with the adjacent colder layer above. Bigelow (1927, p. 546) estimates that "during the first weeks in March the warming affected from below by this source raises the temperature of the deep waters of the inner part of the gulf as rapidly as solar heat warms the surface stratum". By the end of April warming from above has penetrated to a depth of 100 metres in the western side of the basin and in the northeastern side from below to within 15 to 20 metres of the surface (Bigelow 1927, p. 547). The water mass becomes highly stratified over much of the gulf during the summer, the surface layer reaching at times 20°C. or more in the western basin. Relatively low surface temperatures due to turbulence prevail throughout the summer in the eastern coastal area, the cape Sable region and on the offshore banks.

In the bay of Fundy the surface begins to cool early in September and in the more turbulent areas is soon followed by a decline in the lower levels. However, cooling does not become appreciable until considerably later than in the gulf. In deeper, more stable areas (fig. 3) heating of the lower strata may continue into October. The whole water mass reaches a uniform temperature of 6.5° to 7.5°C. in November, and with continued cooling remains substantially the same from top to bottom until April. Minimum values of 1° to 1.5°C. are found at the surface in February or early March.

With a slight warming at the surface in March the water mass again becomes homogeneous at approximately 2°. The increase in surface temperatures varies greatly in different parts of the bay, depending on the intensity of mixing. In the more stable areas (fig. 3A) the upper stratum warms more rapidly and reaches its maximum earlier in the season than in turbulent areas like the Quoddy region (fig. 3B) where the absorbed heat is distributed over a much wider vertical range. The entire Fundy region, however, is subjected to such violent tidal action that temperatures over the greater part of the bay do not usually rise above 12°C.,

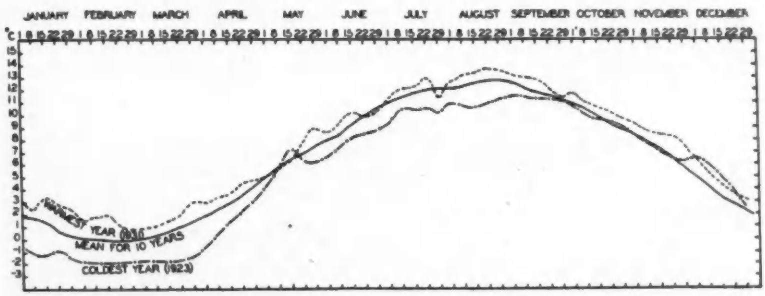


FIGURE 4. Average range of temperature at St. Andrews during the period 1922-1931, and in the coldest (1923) and warmest (1931) years. Based on daily readings.

and, although there is considerable regional variation (Bigelow 1927, p. 591), higher offshore values, when they occur, can have little biological significance, being too restricted in area and of short duration. The maximum temperature (15.13°C.) in 1932 was recorded on August 19.

Of importance to the biologist seeking causes for fluctuations in animal populations is the apparent slight variation in the temperature cycle from year to year in any one locality. This has previously been noted by Bigelow (1927, p. 628) who states, "More or less fluctuation in summer temperature is to be expected in any partially enclosed basin as subject to violent climatic changes as is the gulf of Maine, and where waters of different temperatures meet. What really deserves emphasis is that the yearly changes have been very small during the period of record; certainly not enough to seriously affect the waters of the Gulf as a biologic environment, except perhaps in 1916."

Even in shallow inshore waters affected by ice conditions, and more readily

responding to low air temperatures, the fluctuations are surprisingly small. The warmest (1931) and coldest (1923) years recorded for the period 1922-1931 at St. Andrews, New Brunswick (fig. 4), show a deviation of less than 3°C. above or below the mean. It is improbable that high temperatures, usually of short duration, ever prove fatal to the *neritic* population, but unusually low temperatures over an extended period such as those prevailing at St. Andrews from January

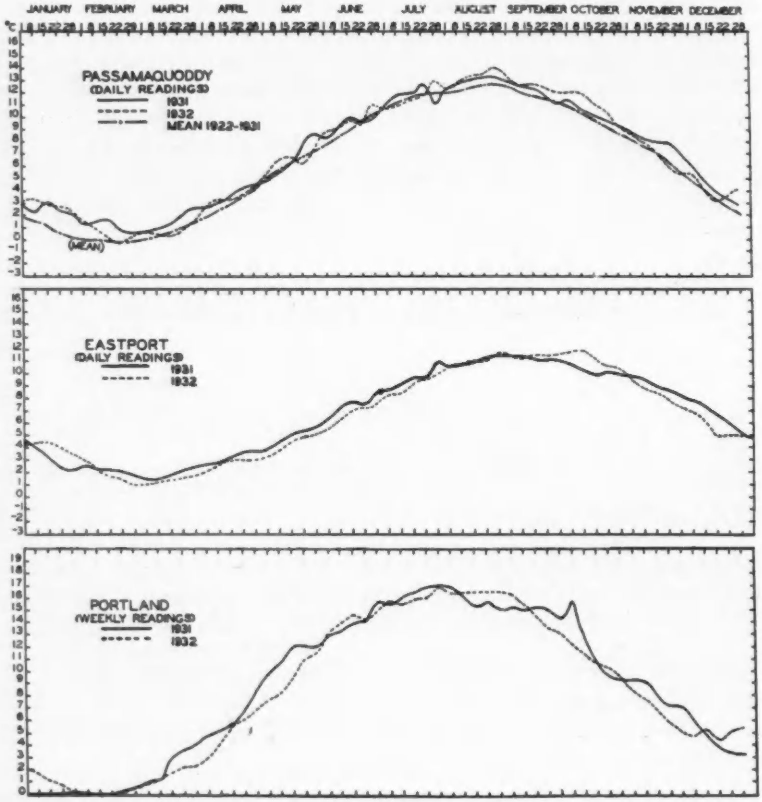


FIGURE 5. Annual range of temperature in 1931 and 1932 at St. Andrews, Eastport and Portland.

to the end of March in 1923 (–1° to –2°C.) no doubt prove destructive to certain members of the benthonic community which in boreal waters appear to have a minimum temperature limit very close to that usually found in their particular locality. In the gulf this would be expected to be approximately 0° to 1°C.

The surface temperature data for St. Andrews indicates that 1931 and 1932 were "warm" years and for the greater part of the year slightly exceeded the mean, especially during late winter and mid-summer. (fig. 5). It was not possible

to construct a mean range for other localities, but the surface temperature records for both Eastport and Portland coincide closely for 1931 and 1932.

Bays in the western part of the gulf appear to respond more quickly to autumnal cooling, and vernal warming, and decline in temperature almost as much as those farther east in more tide swept areas. It is interesting to note that in

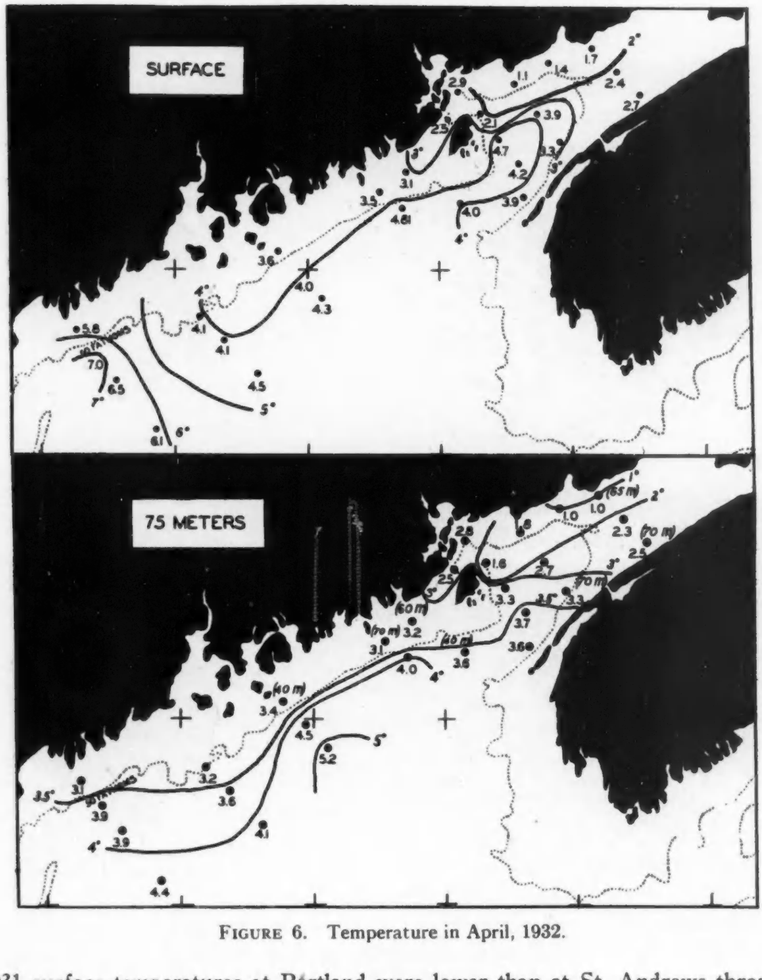


FIGURE 6. Temperature in April, 1932.

1931 surface temperatures at Portland were lower than at St. Andrews throughout the coldest months, January and February. In 1932 a temperature of 1°C. was reached at Portland on January 16, and 0°C. on January 28. The water did not rise above 0°C. until February 23, reaching 2°C. on March 18 and 3°C. by the end of the month. At St. Andrews the temperature did not fall below 1°C. until

February 5, and reached zero only on March 17 at a time when the temperature at Portland had risen 2°C. above the winter minimum. Warming was slower throughout the spring in Passamaquoddy bay, and the temperature did not rise above 2°C. until the end of March. The response in 1932 thus appeared to be about two weeks later at St. Andrews than at Portland during late winter and early spring. The maximum temperature recorded in 1932 at the latter point was 17°C. on July 29-30, and at the former, 14.3°C. on August 30.

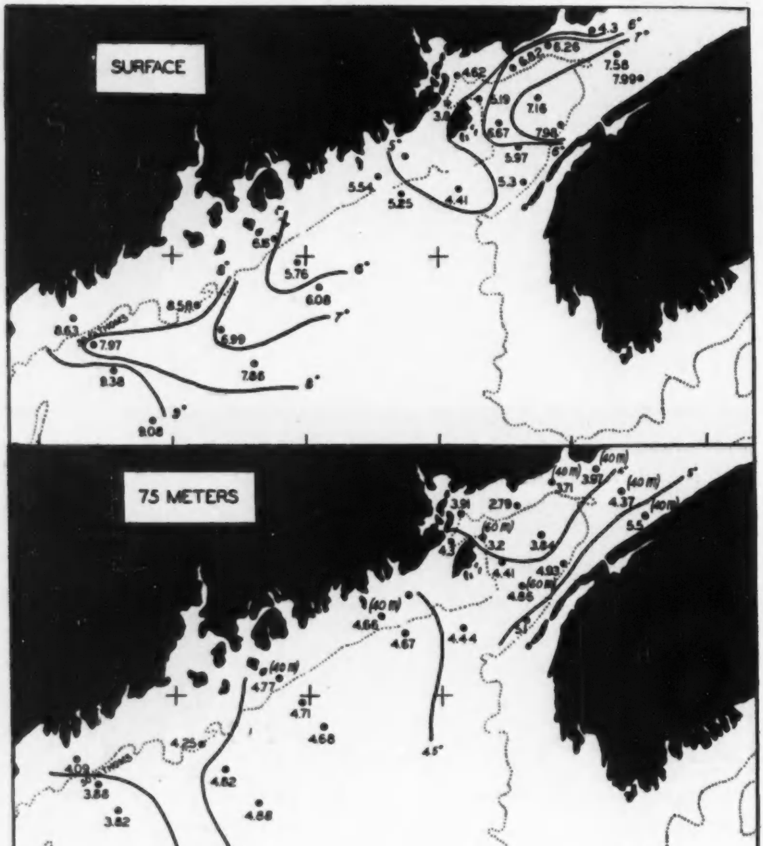


FIGURE 7. Temperature in May, 1932.

HORIZONTAL DISTRIBUTION OF TEMPERATURE IN 1932

For present purposes, the horizontal distribution of high temperatures, low temperatures and relatively homogeneous water, particularly during the periods of restocking, appears to be of greatest biological importance (pp. 310-312). The

present data from April until September (1932) accord so closely with the published records for previous years (Bigelow 1917, 1922 and 1927) that only a brief summary with figures showing seasonal changes will be presented at this time.

When investigations began in late April (cruise 26) the western area had warmed to from 5° to 7°C. (fig. 6), but over the remainder of the gulf and central

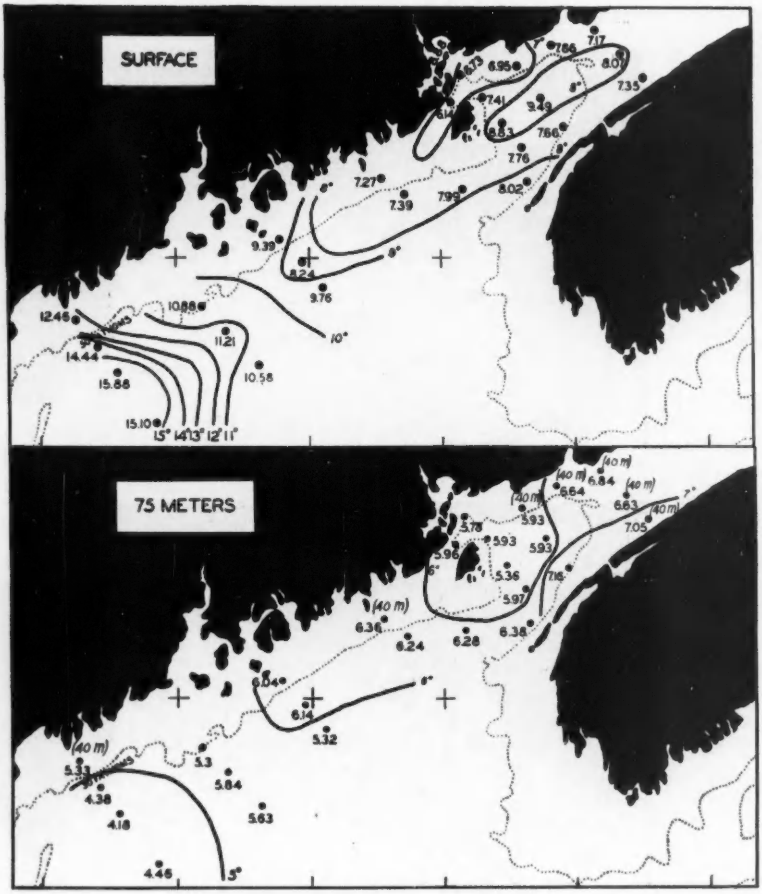


FIGURE 8. Temperature in June, 1932.

basin in the bay surface temperatures ranged from 3° to 4.8°C. The coldest surface water was found along the New Brunswick coast (1.1°C.) influenced by the Saint John outwash. The relative distribution of temperatures at 75 metres (fig. 6) was much the same as at the surface, except that the influence of slope water was detectable at the deepest station off Mount Desert Island.

In May (cruise 27) the upper stratum warmed to at least 5°C. everywhere

except off Saint John, the Quoddy region, and station 34 near Grand Manan bank. West of Mount Desert temperatures ranged from 6° to 9.08°C., and in the more stratified parts of the bay from 6° to 7.99°C. The effect of the cold Nova Scotian current is indicated by a cold band of less than 6°C. extending across the entrance to the bay of Fundy and reaching as far as Mount Desert. Its influence is further detectable in a tongue-like projection of all isotherms along the course of the drift at least as far west as Casco bay.

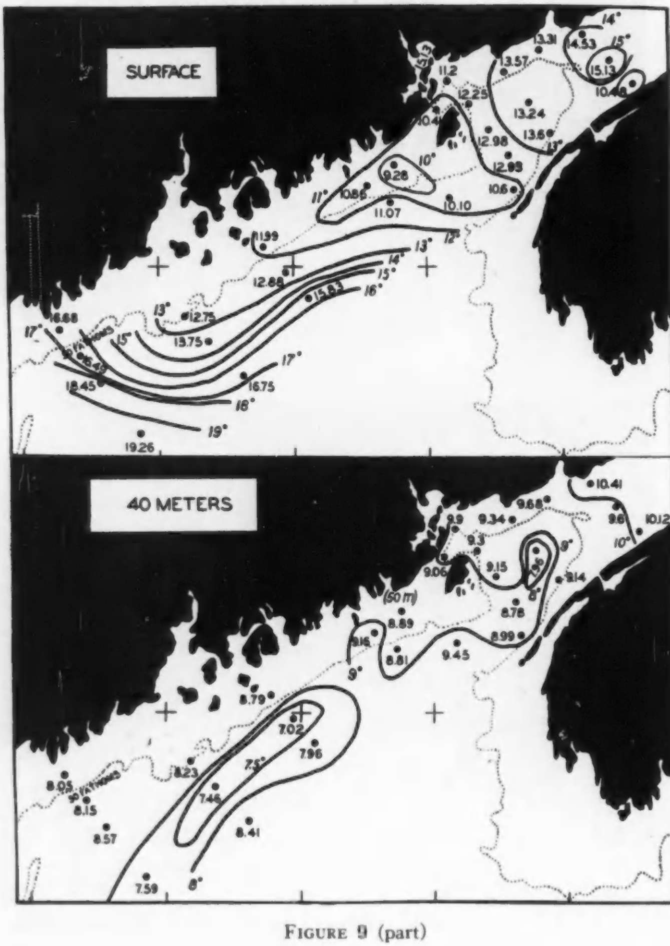


FIGURE 9 (part)

By June (cruise 28) the temperature in the western area exceeded 15°C. decreasing gradually to 10°C. off Penobscot bay, and 7° to 8°C. east of Mount Desert. The coldest surface water (6.14° to 6.95°C.) was found in the Quoddy region and Grand Manan channel. East of Grand Manan temperatures from 8°

to 9.5°C. occurred over the central basin but the greater part of the bay was below 8°C. Below 40 metres the western area after June was coldest, and the bay of Fundy, including the eastern coastal region of the gulf, warmest.

Surface temperatures over the greater part of the gulf ranged from 15° to 19°C. in August, and in the bay from 12° to 14°C. with very localized areas of 10.48° to 15.13°C. (fig. 9). Mixing, indicated by low surface temperatures (9.3° to 11°C.), was most pronounced at this time in the northeastern part of the gulf

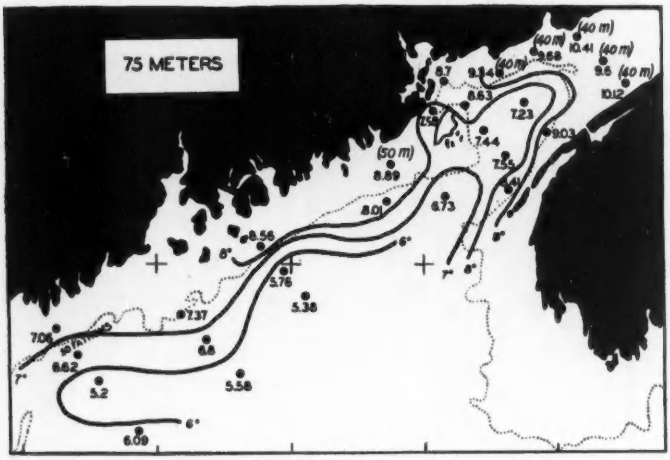


FIGURE 9 (con.) Temperature in August, 1932.

between Petit Manan and Grand Manan, with water of less than 13°C. extending west of Penobscot bay. Temperatures below 7°C. were now restricted to the gulf within the 100 metre contour.

Autumnal cooling had reduced temperatures over the greater part of the gulf by the middle of September (fig. 10). East of Mount Desert to the Quoddy region there had been a slight increase, but elsewhere in the bay of Fundy, due perhaps more to violent mixing at the entrance than to seasonal cooling, surface temperatures, particularly on the Nova Scotian side, had declined from the August maximum. The lowest surface reading was 9.6°C. off Briar Island (sta. 8A).

CIRCULATION

For additional data on the direction and rate of dispersal of eggs and larvae during the important augmentation period in May and June (1932), drift bottles were set out along the lines of zooplankton stations in the gulf of Maine and bay of Fundy. The bottles were of the type used by the U.S. Bureau of Fisheries and equipped with a two-metre drag to reduce wind action. Of 446 liberated 106 have been recovered. (See table II, pp. 214-217.) The probable courses taken by these bottles have been plotted to accord with other hydrographic evidence and with the findings of previous investigators.

The non-tidal circulation in the gulf of Maine is counter clockwise eddying about a central vortex, the location of which varies from off the bay of Fundy to a point from 60 to 70 miles south of Mount Desert island (Bigelow 1927, p. 972). There is some seasonal and annual variation, but the general movement about the gulf is continuous throughout the year. Inflow at the surface is most evident at the eastern side of the gulf, and outflow at the western, past cape Cod, with some discharge around the eastern end of Georges bank. As previously stated, bottom water enters through the eastern channel.

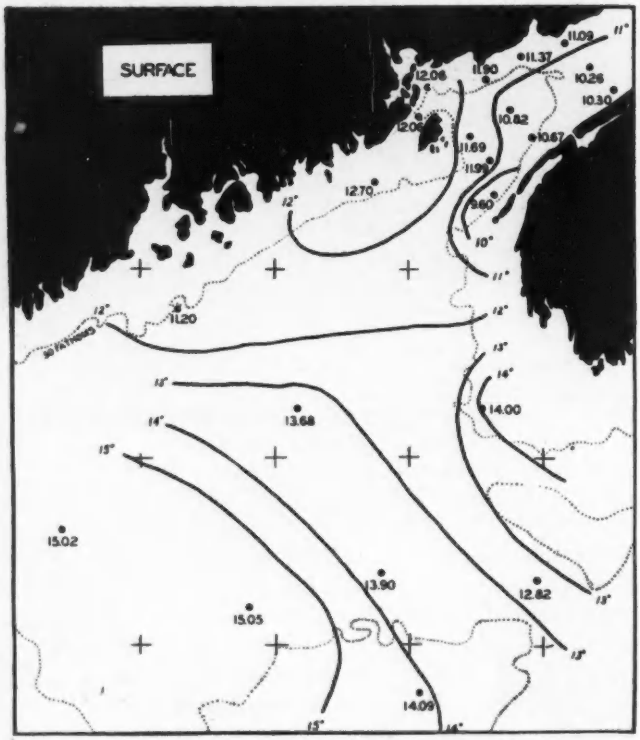


FIGURE 10 (part)

In the inner part of the gulf, west of Mount Desert, the general movement during the summer of 1932 was offshore except close to the islands where drift bottles indicated an along-shore set (series C and D, western part). East of Mount Desert to Grand Manan the general circulatory drift is complicated by the topography and local hydrographical conditions which appear to retard any dominant westerly movement in that sector. This is suggested by the relatively long interval of time before bottles set out in this area were recovered, and also by the zooplankton in which the horizontal variation was more marked than would

be expected along the course of a continuous drift. From the small number of bottles grounding in this area the dominant set would appear to be offshore as far east as Machias, except for a westerly set close to the land. Bigelow's drift bottle results suggest that ". . . such parts of the dominant surface drift as veers westward past Grand Manan does not usually strike the coast of Maine in summer until it has passed the longitude of Mount Desert," (Bigelow 1927, p. 907).

After circling the outer part of the gulf a portion of the drift completes the circuit across the entrance of the bay of Fundy and west along the coast of Maine.

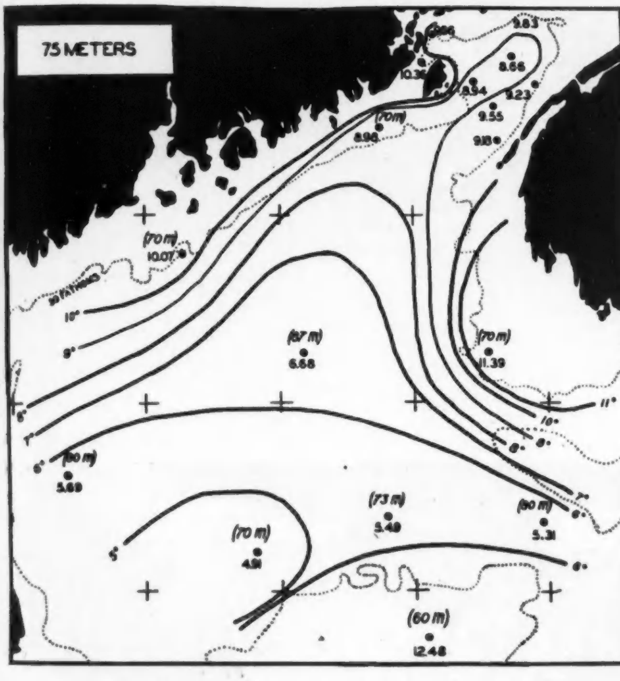


Figure 10 (con.) Temperature in September, 1932.

A branch constituting, according to Bigelow's records (1927, p. 906), the greater volume, continues east into the bay on the Nova Scotian side. Bigelow (1927, p. 972) found that "This Nova Scotian side of the gulf of Maine eddy also receives water in some volume from the dead zone off cape Sable in summer, and in some years a westerly drift past cape Sable into the gulf of Maine persists from spring through summer." Close to the southern shore the indraft into the bay of Fundy extends to the headwaters, but the major portion follows the 100-metre contour to form a second (counter clockwise) eddy whose outer margin does not extend far beyond the slope of the basin. It passes west along the New Brunswick coast and out of the bay along the eastern and southern sides of Grand Manan where

it becomes a part of another (clockwise) eddy movement having Grand Manan as a vortex. This latter eddy was suggested by Bigelow (1927, p. 973) who described an eastward drift along the southern shore in Grand Manan channel

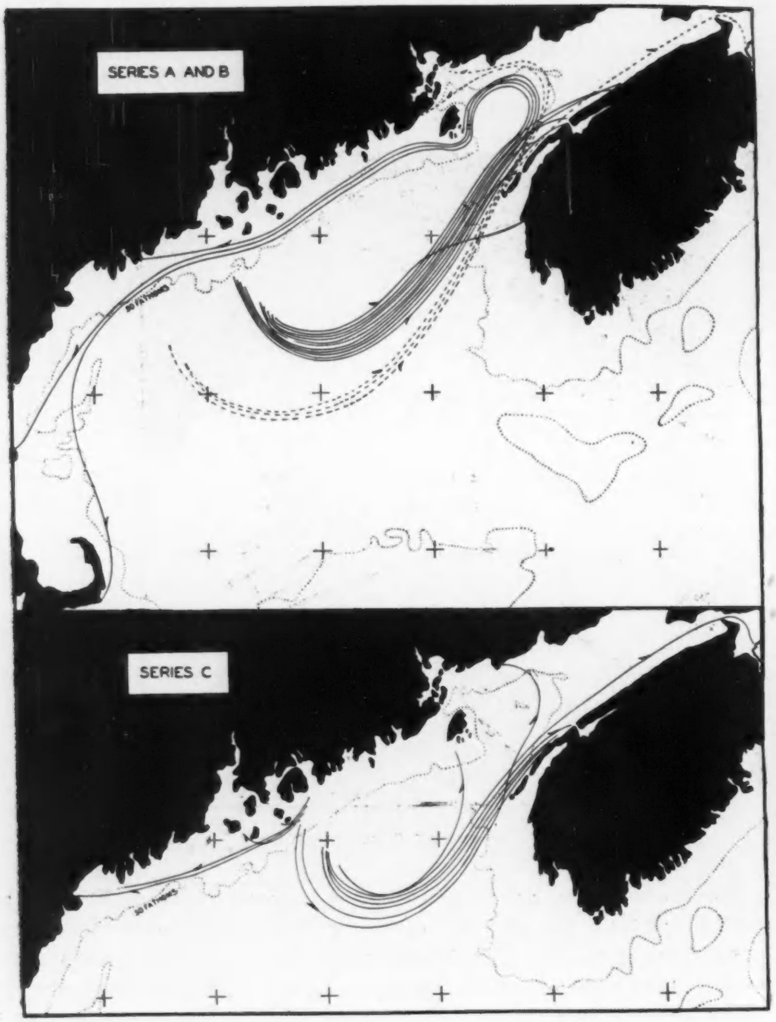


FIGURE 11 (part)

(Mavor 1922; Watson 1936), a movement involving, however, only a small part of the water leaving the bay—the major drift appears to be west to the coast of Maine.

The Quoddy region and the Grand Manan channel lie out of the main course of the Fundy drift and form a sort of pocket in which biological interchange with outer waters is apparently relatively slow. Surface waters entering the region

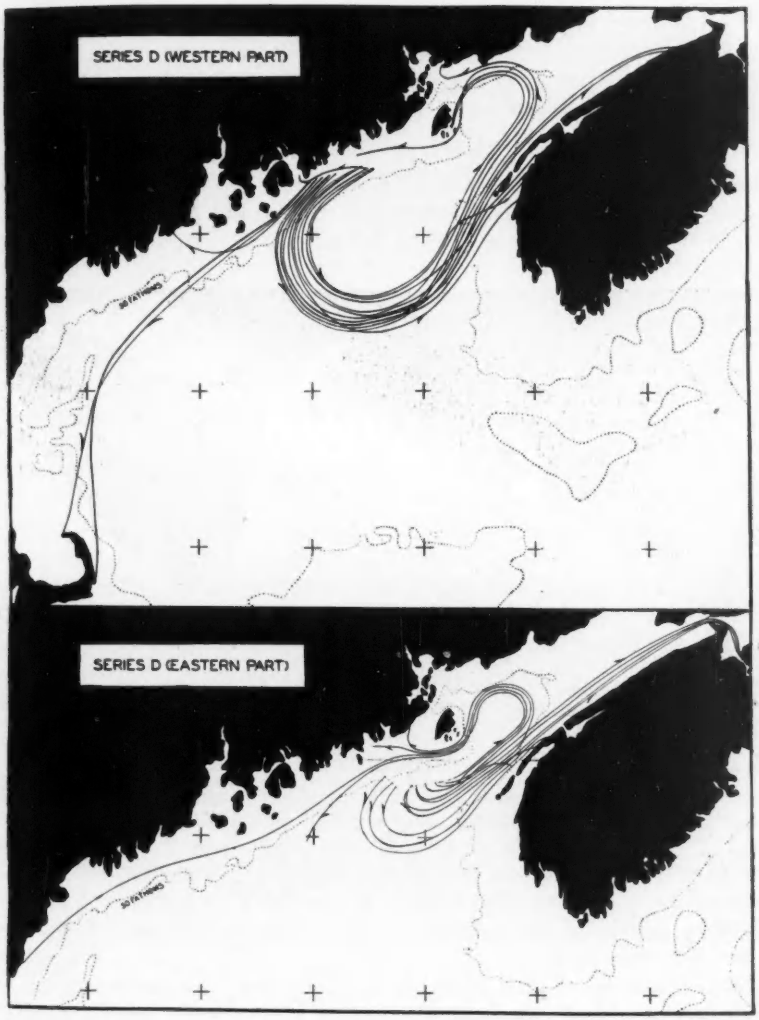


FIGURE 11 (con.). Assumed drifts of bottles recovered from series A-D, released in the gulf of Maine, May 24-30, 1932.

appear to be derived largely from the along-shore area to the east, relatively barren in zooplankton. Drift bottles showed little evidence of surface indraft from offshore except those set out in the immediate vicinity which moved into the

western passage, out through the Lubec narrows and west along the north shore of Grand Manan channel. But one bottle entered Passamaquoddy bay (fig. 13), apparently through one of the Letite passages.

The principal exchange of waters in the Quoddy region appears to involve an indraft of heavy bottom water through the channel between the Wolves bank and Grand Manan, and, after thorough mixing with light river water, an outflow at an intermediate level. This movement is not sufficiently active to be detectable in available biological evidence.

RATE OF DRIFT

Knowing the approximate rate of development of pelagic eggs and larvae (confined largely to the upper strata) taken at any point along the course of a known drift, as in the gulf of Maine, the velocity of the transporting current

FIGURE 12. Assumed drifts of bottles recovered from series H-J, released in the gulf of Maine on June 26-28, and in the Roseway bank region on July 16, 1932.

affords a means of estimating roughly the possible distance traversed and the probable source of supply. This method has previously been applied in the gulf of Maine in considering the dispersal of *Gadus callarias* eggs and larvae (Fish 1928 and Schroeder 1930).

The probable rate of drift in the region at certain seasons has been estimated by several investigators. In the bay of Fundy in May, 1930, Hachey's records indicated a minimum rate of four miles per day (1 mile equals 1.6 kilometres) around the circuit of the basin, and Mavor (1922, p. 16) during the late summer of 1919 reported a minimum velocity of four miles per day along the Nova Scotian shore and five miles per day along the coast of New Brunswick.

In the gulf drift bottles set out by Mavor in August travelled from the bay

of Fundy to cape Cod in 73 to 80 days at a rate of four miles per day (in a straight line). Along the outer course of the eddy, east from cape Ann, Bigelow (1927, p. 888) in August, 1923, found a velocity of three to four miles per day perhaps increasing to five or six miles near Nova Scotia. The quickest passage consumed 56 days, a rate of 4.7 miles along the assumed eddying route. Of three bottles set out off cape Ann in April, 1926 (Bigelow 1927, p. 878) two reached Digby county, Nova Scotia, in 73 and 77 days respectively, and one Lepreau harbour, New Brunswick, in 94 days.

Thus during the spring and summer, covering the most important periods of zooplankton production, the results of previous observers would indicate an average rate of about four miles per day about the periphery of the gulf and bay, perhaps increasing to five or more miles near the southern entrance to the bay and along the coast of New Brunswick, and rarely falling below three miles per day.

Bay of Fundy in 1932. In the bay of Fundy where the course of the set is fairly evident, drift bottle velocities in May and June, 1932, were found to accord very well with previous records. Figure 14A shows the points of liberation and recovery together with the interval of the drift of bottles found floating or probably obtained shortly after grounding. Three bottles set out south of Grand Manan on a line from the Wolves bank to Briar Island (series E) were found drifting along the New Brunswick coast between Saint John and Dipper harbour in 16 to 17 days, indicating a velocity of three and four tenths to four miles per day (bottles no. 106, 123, 136). Along the eastern side of Grand Manan the drift was more rapid, approximating five miles (bottle no. 84), and around the western margin of the eddy four to four and six tenths miles (bottles nos. 30, 89, 101). East of Digby gut the velocity of the set along the Nova Scotian coast was probably less than one mile per day, as the minimum interval of drift of bottles from the entrance to the vicinity of Minas basin was 82 days and the average 106 days.

Pelagic eggs and larvae entering from the gulf of Maine at this time would thus be expected to reach the New Brunswick coast in two to three weeks and might complete a circuit of the bay in from three to four weeks. Eggs produced along the north coast west of Saint John to Grand Manan could be transported beyond the confines of the bay in from one to two weeks, although a considerable proportion, particularly those produced within the 100 metre contour, might remain within the bay, following around the inner part of the eddy. One would look for the largest concentrations of zooplankton over the central basin in the vortex of the circuit.

Gulf of Maine in 1932. In the gulf, except in the case of the along-shore drift where the course of the set is evident, it is not possible to accurately determine the velocity from drift bottles without supporting current measurements. By enlarging or contracting the arc of the assumed drift tract, the apparent velocity of bottles circling the gulf may be made to vary widely. Lacking current metre data for the period of the present investigations, it has been considered advisable to use the observed interval of time required for the passage of drift bottles be-

tween various points, rather than the estimated velocity, for application to zooplankton dispersal in the gulf of Maine. However, since the present data on the rate of nontidal circulation in the bay of Fundy accords with previous records, it may be assumed that velocities in the gulf were equally comparable in May and June in 1932, and probably averaged about three to four miles per day.

The velocity of the drift about the gulf is greatest in the spring, and thereafter varies somewhat in different localities both in rate and direction according

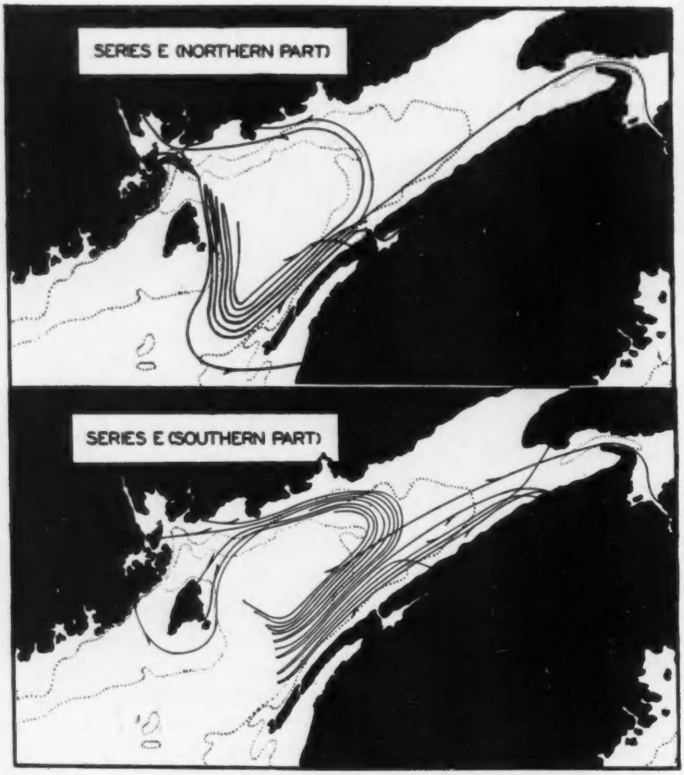


FIGURE 13 (part)

to the location of the centre of the circulatory movement. In regard to seasonal variations Bigelow (1927, p. 975) found ". . . the circulation centering chiefly around the Eastern Channel in March with velocities greatest as it drifts inward along the eastern side and outward along the western side of the latter. From March to April, however, the center of circulation shifts northward across the basin; the movement slackens in the southeastern part of the area, and the coastwise drift gathers strength. Shortly thereafter, when the water of the Nova

Scotian current floods into the Gulf from the east, the heavy center is shifted southwestward across the Gulf."

In the late summer (August to October, 1922 and 1923) with the vortex of the gulf of Maine eddy located some 40 to 60 miles south of Mount Desert, Bigelow (1927, p. 904-6) concluded that due to the circuitous route, bottles liberated off Mount Desert probably covered about as long a distance to Nova Scotia as those from off cape Elizabeth, and that the former drifted westward between Penobscot

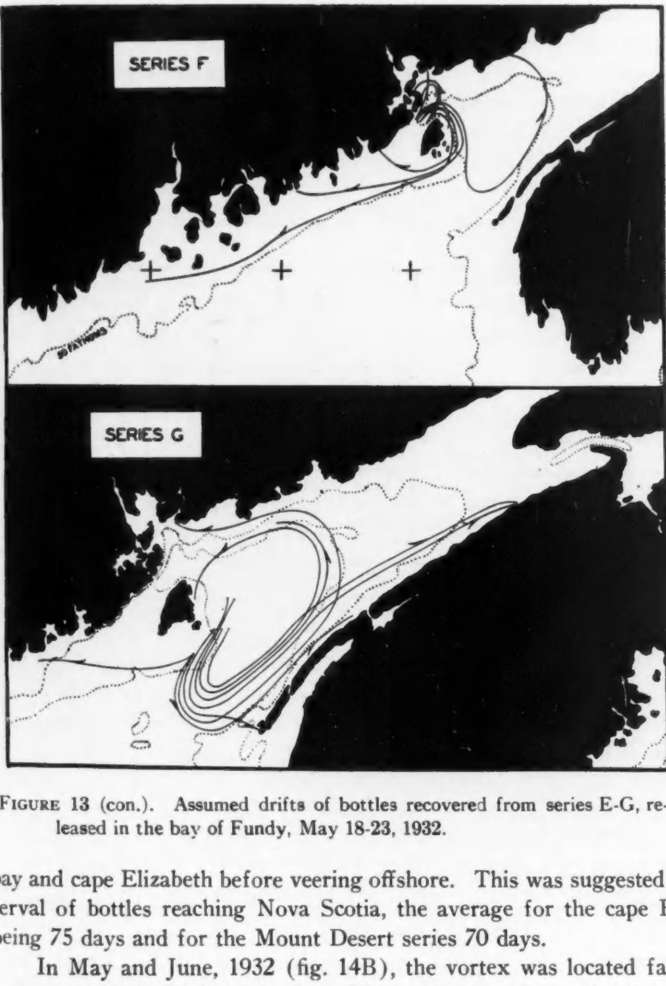


FIGURE 13 (con.). Assumed drifts of bottles recovered from series E-G, released in the bay of Fundy, May 18-23, 1932.

bay and cape Elizabeth before veering offshore. This was suggested by the time interval of bottles reaching Nova Scotia, the average for the cape Elizabeth series being 75 days and for the Mount Desert series 70 days.

In May and June, 1932 (fig. 14B), the vortex was located farther east than in August, 1923. Drift bottles from Mount Desert and even farther east entered the bay of Fundy and grounded on the New Brunswick shore in 49 to 53 days, whereas bottles from off Casco bay yielded few returns, those reaching the same

area requiring 102 days. With the centre of the eddy in the extreme northeastern part of the basin, the drift probably veered offshore in the vicinity of Mount Desert. With an average velocity of four miles a day, bottles of series C and D (western part) placed between Mount Desert and Moose Peak could hardly have drifted much farther west than Blue Hill bay. To reach the New Brunswick coast in 49 to 53 days and at the same time travel westward to points between Penobscot bay and cape Elizabeth before veering offshore would have required an average velocity of six to seven miles, a rate obviously excessive. The higher percentage of returns from bottles placed east of Casco bay (25 per cent east of Mount Desert, 17 to 19 per cent Mount Desert to Penobscot bay, 7.5 per cent Casco bay) offers further evidence that these took a more direct and inside route to Nova Scotia.

The average and minimum intervals of drift between various points in the gulf of Maine and bay of Fundy in 1932 are shown in the following table.

Considering first the western area, eggs and larvae produced in the region

TABLE I. Distribution and interval of drift of bottles set

Area					Gulf of Maine			
					East of Mt. Desert			West
		Set out	Returned			Interval		
			No.	%	%	Min.	Av.	%
A	Off Casco bay	May 31	3	7.5	33.3	102	102	-
B	Off Penobscot bay	May 30	11	19.3	-	-	-	27
C	Mt. Desert to Great Duck island	May 26-7	4	25	-	-	-	100
D	Off Mt. Desert island	May 27	7	17.5	-	-	-	-
D	Off Moose Peak to Frenchmans bay	May 24	15	25	13	7	67.5	20
D	Off Grand Manan bank to Moose Peak	May 24	11	25	27	83	115	10
E	So. Wolves Bank (northern part)	May 23	20	31	15	8	20	-
E	So. Wolves Bank (southern part)	May 23	7	35	-	-	-	-
F	Grand Manan Channel	May 18	8	33	25	26	115	12.5
G	East and south of Grand Manan	May 18	8	25	12.5	166	166	-
H	East and south of Grand Manan	June 26	7	25	-	-	-	14
I	Off Mt. Desert	June 28	4	18.2	-	-	-	-

*Average of 5 of 7 bottles = 49 days (1 = 140; 1 = 203)
#Average of 3 of 5 bottles = 59 days (1 = 129; 1 = 166)
"Average of 3 of 4 bottles = 109 days (1 = 176)

between Mount Desert and Penobscot bay in May and June might have reached the bay of Fundy in a minimum interval of 31 days and an average of from 50 to 60 days. This estimate applies only to objects in the surface drift. The rate of subsurface movement, although not yet determined, is slower. Farther west, allowing 25 to 30 days (p. 209) for the circuit of the bay of Fundy, the two bottles from off Casco bay recovered in the vicinity of the Quoddy region after 102 days, probably reached the Nova Scotian coast in from 70 to 75 days, a figure approximating some of Bigelow's records for June, 1922.

The eastern region (east of Petit Manan), with relatively homogeneous water resulting from violent mechanical (tidal) mixing, forms a "dead area" in which the dominant set may, at least at times, be retarded and bottles retained locally for some time. This is indicated by the average period of drift (115 days) for all bottles set out between Frenchmans bay and Grand Manan bank (series D and H). Those liberated between Mount Desert and Moose Peak reached the

Nova Scotian coast in a minimum of 50 days and an average of 94 days. Between Moose Peak and Grand Manan bank the minimum interval of passage to Nova Scotia was 37 days, and the average 70 days.

Thus zooplankton produced west of Mount Desert, if it remained in the surface layer, might be expected to enter the bay of Fundy at an age of from one to two months, covering the greater distance as quickly, if not quicker, than forms produced in the coastal region east of Frenchmans bay. In the latter area a significant portion of such locally produced animals as survive in turbulent waters would have ample time to become well advanced in development within the immediate region.

Those branches of the coastwise drift which continue west past cape Cod and around the eastern end of Georges bank do not enter into the present problem involving the origin of the zooplankton population of the bay of Fundy. They do, however, transport out of the gulf considerable quantities of zooplankton pro-

out in the bay of Fundy and gulf of Maine in May and June, 1932

of Mt. Desert		Nova Scotia East to Digby			Nova Scotia Minas Basin			New Brunswick coast			Grand Manan		
Interval			Interval			Interval			Interval			Interval	
Min.	Av.	%	Min.	Av.	%	Min.	Av.	%	Min.	Av.	%	Min.	Av.
-	-	-	-	-	33.3	115	115	33.3	102	102	-	-	-
139	172	64	31	84*	-	-	-	-	-	-	9	118	118
6	21.4	-	-	-	-	-	-	-	-	-	-	-	-
-	-	58	32	57.5	14	107	107	14	114	114	14	28	28
159	19.7	34	50	94*	13	110	114	7	132	132	13	114	129
235	235	27	37	69.7	36	109	126"	-	-	-	-	-	-
-	-	20	15	88	10	111	113	40	8	54	15	3	47
-	-	14	36	36	57	82	106	29	16	23	-	-	-
181	181	-	-	-	-	-	-	50	12	36	12.5	111	111
-	-	25	79	106	25	113	114	25	30	66	12.5	51	51
139	139	14	72	72	29	78	102	14	49	49	29	73	80.5
-	-	25	199	199	25	108	108	25	53	53	25	199	225

duced along the coast of Maine. Schroeder (1930, p. 87) has estimated, on the basis of previous drift bottle and current measurements, that during the winter and spring coastal drift velocities from eastern Maine to cape Ann range from five to eight miles per day, and across Massachusetts bay from two to five miles. Velocities of this order of magnitude would permit pelagic eggs and larvae of even temporary members of the plankton community, such as the cod, to travel from eastern Maine to beyond cape Cod before seeking the bottom, a condition which has led Schroeder (1930, p. 90) to conclude that the region east of cape Elizabeth to the bay of Fundy constitutes one of the most probable sources of cod fry found on the bottom on Nantucket shoals. Unfortunately it is not possible to estimate on the basis of available data what proportion of the zooplankton population is removed from the gulf in this manner.

TABLE II. Drift bottle records; May and June, 1932

Series A: May 31, 1932; four bottles at intervals of 5 miles on a line running 141° for 45 miles from a point 5 miles off Sequin island: Nos. 366-405.

No.	Released						Recovered	Date 1932	Interval (days)
	Latitude			Longitude					
	°	′	″	°	′	″			
371	43	09	54	69	11	20	L'Etang river, Charlotte Co., N.B.	Sept. 9	102
373	43	09	54	69	11	20	Eastern side of Moose cove, Me.	Sept. 9	102
379	43	16	42	69	19	00	3 miles west of Harbourville, Kings Co., N.S.	Sept. 22	115

Series B: May 30, 1932; four bottles at intervals of 2 miles on a line running 137° for 30 miles from a point 5 miles off Matinicus rock. Nos. 309-55.

No.	Released						Recovered	Date 1932	Interval (days)
	Latitude			Longitude					
	°	′	″	°	′	″			
309	34	42	19	68	47	00	3 miles east of Digby gut, Bogey brook, Digby Co., N.S.	July 19	51
314	34	40	56	68	45	15	4 miles W.N.W. Boars Head light, Tiverton, N.S.	July 8	40
320	34	39	33	68	43	30	Small point (near Bath), Me.	Oct. 9	139
325	34	38	10	68	41	45	2 miles west of Centreville, N.S.	June 29	31
338	43	32	38	68	33	45	Near coast guard station south of Straitmouth island (near Rockport), Mass.	Dec. 4	189
342	43	31	15	68	32	00	5 miles west of Pt. Prim light, N.S.	June 30	32
344	43	31	15	68	32	00	¼ mile from Hampton wharf, Hampton, N.S.	Dec. 18	203
348	43	29	52	68	30	15	Abreast Old Harbor coast guard station, Chatham, Mass.	Dec. 3	188
349	43	29	52	68	30	15	Cow passage, White Head, Grand Manan, N.B.	Sept. 24	118
352	43	28	29	68	28	30	Youngs cove, Annapolis Co., N.S.	Aug. 28	91
355	43	27	06	68	26	45	Cape cove (near Mavillette) Digby Co., N.S.	Oct. 16	140

Series C: May 26-27, 1932; four bottles at intervals of 2 miles on a line from Bakers island to Great Duck island and then 137° for 20 miles. Nos. 253-256 (May 26); 257-308 (May 27).

No.	Released						Recovered	Date 1932	Interval (days)
	Latitude			Longitude					
	°	′	″	°	′	″			
256	44	15	15	68	10	15	South of Great Hen island (near Swan island), Me.	May 31	6
257	44	11	45	68	10	15	Cundys harbor, Casco bay, Me.	July 24	58
260	44	11	45	68	10	15	High Head point, Casco bay, Me.	June 23	28
267	44	05	00	68	10	15	Big Green island (near Matinicus), Me.	June 10	15
271	44	03	36	68	08	21	Chance harbour, St. John Co., N.B.	Sept. 17	114
273	44	02	12	68	06	32	1 mile east of Burns cove, Digby Co., N.S.	Aug. 29	95
290	43	56	36	67	59	16	Off Centreville, Digby Co., N.S.	July 13	47
293	43	55	12	67	57	27	Life saving station, Bay View, Digby Co., N.S.	July 21	56

TABLE II, Series C.—*Continued*

No.	Released						Recovered	Date 1932	Interval (days)
	Latitude			Longitude					
	°	′	″	°	′	″			
294	43	55	12	67	57	27	2 miles off Point Prim light, Digby Co., N.S.		
296	43	55	12	67	57	27	7 miles south of Gannet Rock light, Grand Manan, N.B.	June 23	28
308	43	51	00	67	52	00	3 miles west of Harbourville, N.S.	Sept. 11	107

Series D: May 24, 1932; four bottles at intervals of 2 miles on a line running 124° for 10 miles from a point 5 miles off Moose Peak, and then 84° for 20 miles. Nos. 149 to 252.

No.	Released						Recovered	Date 1932-3	Interval (days)
	Latitude			Longitude					
	°	′	″	°	′	″			
149	44	21	30	66	47	00	Near Harbourville, Kings Co., N.S.	Sept. 10	110
155	44	21	18	66	49	46	Johnson cove, Rogue bluffs, Me.	Oct. 16	146
160	44	21	06	66	52	32	10 miles W.N.W. of Boars head, Tiverton, N.S.	July 28	75
165	44	20	42	66	58	04	East of Mount Desert rock	Aug. 15	83
173	44	20	18	67	03	36	Diligent river, N.S.	Nov. 15	176
174	44	20	18	67	03	36	Moody beach, Me.	Jan. 13	235
178	44	20	06	67	06	22	½ mile N.E. of Little River light, Cutler, Me.	Sept. 16	116
180	44	20	06	67	06	22	2 miles west of Centreville, N.S.	June 29	37
190	44	19	30	67	14	40	3 miles west of Harbourville, N.S.	Sept. 10	109
194	44	20	50	67	17	00	Twiners brook, near Harbourville, N.S.	Sept. 10	109
201	44	22	54	67	22	00	Burns cove, Digby Co., N.S.	Aug. 29	97
211	44	24	58	67	27	00	Ross island, Grand Manan, N.B.	Oct. 15	145
212	44	24	58	67	27	00	Grosses Coques, Digby Co., N.S.	Nov. 5	166
213	44	25	00	67	29	06	Nauset harbor, cape Cod, Mass.	Oct. 29	159
215	44	25	00	67	29	06	7 miles S.W. of Boars head, N.S.	July 14	51
218	44	23	00	67	31	12	Cheneys island, Grand Manan, N.B.	Sept. 14	114
223	44	22	00	67	33	18	Victoria harbour, Kings Co., N.S.	Sept. 18	118
224	44	22	00	67	33	18	Comeauville wharf, Digby Co., N.S.	Sept. 29	129
233	44	19	00	67	39	36	Gilbert cove, Digby Co., N.S.	Aug. 7	75
237	44	18	00	67	41	42	White cove, St. Bernard, N.S.	July 13	50
240	44	18	00	67	41	42	Near Victoria wharf, N.S.	Sept. 10	110
243	44	18	15	67	52	00	½ mile N.W. of Great Wass island coast guard station, Me.	Sept. 28	128
245	44	18	30	67	59	00	East side Huppers island, Port Clyde, Me.	Nov. 2	163
248	44	18	30	67	59	00	Big Sturgeon cove (near L'Etang), N.B.	Oct. 2	132
249	44	18	45	68	05	00	Race Pt. light, Provincetown, cape Cod, Mass.	Jan. 28	250
251	44	18	45	68	05	00	2 miles N.E. of Egg rock, Frenchmans bay, Me.	May 30	7

TABLE II.—*Continued*

Series E: May 23, 1932; four bottles at intervals of two miles on a line running 142° for 30 miles from a point 3 miles off White Horse island, and then 167° for 10 miles. Nos. 65 to 148.

No.	Released						Recovered	Date 1932	Interval (days)
	Latitude			Longitude					
	°	′	″	°	′	″			
65	44	57	09	66	47	39	Broad cove, Esteys head, Eastport, Me....	May 30	8
67	44	57	09	66	47	39	Adams island, N.B.	June 9	18
69	44	55	51	66	46	12	Baileys Mistake harbor (near Jims head) Me.	May 30	8
73	44	55	33	66	44	45	2 miles from W. Quoddy life saving station, Lubec, Me.	June 7	16
75	44	55	33	66	44	45	Near Meteghan river wharf, N.S.	Nov. 5	167
76	44	55	33	66	44	45	Seeleys basin, N.B.	May 31	9
78	44	53	15	66	43	18	Tower Granville, Annapolis Co., N.S.	Oct. 17	148
80	44	53	15	66	43	18	Campbells cove, East Dipper harbour, N.B.	Oct. 26	157
84	44	51	57	66	41	51	1 mile north of Old Proprietor ledge, Grand Manan, N.B.	May 25	3
85	44	50	39	66	40	24	3½ miles W. of Harbourville, N.S.	Sept. 11	116
89	44	49	21	66	38	57	6 miles off Pt. Prim light, N.S.	June 6	15
90	44	49	21	66	38	57	Bocabec bay, Charlotte Co., N.B.	Oct. 28	159
101	44	45	27	66	34	36	Gullivers cove, Digby Co., N.S.	June 14	23
106	44	44	09	66	33	09	12 miles S.E. of Musquash light, N.B.	June 8	17
111	44	42	51	66	31	42	3½ miles west of Harbourville, N.S.	Sept. 11	111
117	44	40	15	66	28	48	Whale cove, North head, Grand Manan, N.B.	June 19	28
118	44	40	15	66	28	48	Cheneys island, Grand Manan, N.B.	Sept. 11	111
123	44	38	57	66	27	21	7 miles off Musquash light, N.B.	June 7	16
125	44	37	39	66	25	54	Eastern end Bains island (near Deer island) N.B.	July 6	45
126	44	37	39	66	25	54	¼ mile off Moose River point, Me.	June 27	36
129	44	35	03	66	24	27	N. Moose island (near Beaver harbour), N.B.	June 20	29
133	44	33	45	66	23	00	Near Victoria harbour, Kings Co., N.S.	Sept. 18	119
136	44	33	45	66	23	00	11 miles S.E. Lorneville breakwater, N.B.	June 7	16
139	44	28	00	66	21	10	3 miles E. of Parkers cove wharf, Annapolis Co., N.S.	June 27	36
143	44	28	00	66	21	10	¾ mile east of Morden breakwater, N.S.	Sept. 10	110
145	44	23	30	66	20	00	Victoria harbour, N.S.	Sept. 11	111
147	44	23	30	66	20	00	In Advocate harbour, N.S.	Aug. 13	82

Series F: May 18, 1932; four bottles at intervals of 1 mile on a line from West Quoddy Head to Whale Cove. Nos. 41 to 46.

No.	Released						Recovered	Date 1932	Interval (days)
	Latitude			Longitude					
	°	′	″	°	′	″			
45	44	48	15	66	54	39	Spruce island, Charlotte Co., N.B.	May 30	13
46	44	48	15	66	54	39	Between Chance and Dipper harbours, Charlotte Co., N.B.	Aug. 28	103
51	44	47	48	66	53	33	South end of Low Duck island, Grand Manan, N.B.	Sept. 6	111
54	44	47	21	66	52	27	½ mile north of Little River light, Me.	June 12	26
55	44	47	21	66	52	27	Petit Manan island, Me.	Nov. 16	183
62	44	46	27	66	50	15	Wooden Ball island (off Rockland), Me.	Nov. 14	181
63	44	46	27	66	50	15	Herring cove, Campobello island, N.B.	May 29	12
64	44	46	27	66	50	15	Wilsons Beach, Campobello island, N.B.	June 2	16

TABLE II.—*Continued*

Series G: May 18, 1932; two short sections along the south-east side of Grand Manan; (1) four bottles (nos. 25-32) at 11½ and 16 miles off Swallow Tail light (93°); (2) four bottles (nos. 13 to 24) at 3, 5, and 8½ miles off the northern end of White Horse island (95°). May 19, 1932; four bottles (nos. 1 to 12) at three points off Old Proprietor whistle; 4 miles (278°), 3 miles (217°), and 4 miles (154°).

No.	Released						Recovered	Date 1932	Interval (days)
	Latitude			Longitude					
	°	′	″	°	′	″			
1	44	32	43	66	43	45	Pea Pt. light, N.B.	Aug. 28	102
2	44	32	43	66	43	45	Bear cove, Digby Co., N.S.	Sept. 26	132
4	44	32	43	66	43	45	Morses point (near Popham beach), Me.	Oct. 30	166
13	44	38	18	66	33	00	Long island, N.B.	July 8	51
14	44	38	18	66	33	00	½ mile E. of Morden breakwater, N.S.	Sept. 10	115
19	44	38	20	66	36	25	2 miles N.W. from Whipple point, Briar island, N.S.	Aug. 5	79
26	44	45	25	66	32	15	West side Morden breakwater, N.S.	Sept. 9	113
30	44	45	20	66	28	00	10 miles S.S.W. of Negro head, N.B.	June 17	30

Series H: June 26, 1932, four bottles at intervals of 5 miles on a line running 124° for 15 miles from a point 5 miles off Moose Peak, and then 76° for 15 miles. Nos. 406 to 432.

No.	Released						Recovered	Date 1932	Interval (days)
	Latitude			Longitude					
	°	′	′	°	′	″			
413	44	20	30	67	00	44	7 miles east of Digby, Delaps cove, N.S.	Sept. 5	72
414	44	20	30	67	00	44	Bennetts bay, Kings Co., N.S.	Oct. 31	128
419	44	20	00	67	07	36	2 miles N.E. of North head, Grand Manan, N.B.	Sept. 6	73
423	44	19	30	67	14	28	Whale cove, North head, Grand Manan, N.B.	Sept. 21	88
425	44	22	15	67	20	43	Adams island, N B.	Aug. 13	49
426	44	22	15	67	20	43	3 miles west of Harbourville, N.S.	Sept. 11	78
427	44	22	15	67	20	43	Point of Pines, Revere, Mass.	Nov. 11	139

Series I: June 28, 1932; four bottles at intervals of four miles on a line running 137° for 20 miles from a point 5 miles off Great Duck island, Nos. 433 to 454.

No.	Released						Recovered	Date 1932-3	Interval (days)
	Latitude			Longitude					
	°	′	″	°	′	″			
434	44	04	30	68	11	00	Seeleys cove, Charlotte Co., N.B.	Aug. 19	53
437	44	01	48	68	07	14	Advocate beach near light, N.S.	Oct. 13	108
438	44	01	48	68	07	14	Gullivers cove, Rossway, Digby Co., N.S.	Sept. 26	91
447	43	56	24	67	59	42	White Head island, Grand Manan, N.B.	Feb. 2	251
450	43	52	42	67	55	56	Meteghan Centre, Digby Co., N.S.	Jan. 12	199

Quantitative Zooplankton Distribution

In considering zooplankton volumes one must distinguish between abundance (richness) of the adult population and productivity. The difference results from the time interval involved in the development of planktonic animals, which may range from a few weeks to several months. With the active circulation in the gulf of Maine it is probable that very few, if any, of the offshore species reach maturity very near their point of origin. A locality might thus be relatively unproductive and yet at times harbour an abundant population consisting largely of immigrants from other breeding areas so situated as to serve as sources of supply. Such a condition exists in Frenchmans bay. The quantitative distribution of the adult stock, therefore, can be considered to serve as a measure of the result of production on various areas but does not in itself necessarily indicate the source

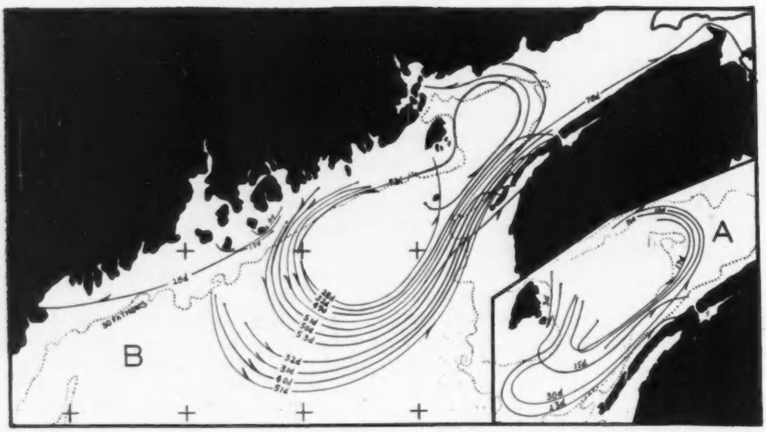


FIGURE 14. Maximum interval of drift of certain bottles released in (A) the bay of Fundy on May 19-23, and (B) the gulf of Maine in May and June, 1932.

of origin. To gauge the productivity of an area one must consider the amount of actual successful propagation taking place there. This, however, involves different methods of analysis, which have been treated separately elsewhere (Fish 1936a, 1936 b and c).

The quantitative distribution and seasonal changes in the abundance of zooplankton in the gulf of Maine as described in detail by Bigelow (1926, p. 78) agree very well with the present findings. The purpose here will be to consider the bay of Fundy in relation to the gulf and to compare the records for 1931-32 in the latter area with those previously obtained. Unfortunately, due to different methods used, it is not possible to compare the actual volumes obtained in the present investigation with those of Bigelow. The relative differences in quantitative distribution are comparable however.

In analyzing the collections prior to April, 1932, when only horizontal towing was carried on (p. 194), the volumes obtained by 20 minute hauls with a closing metre net at the surface and lower levels have been combined and the results adjusted for a towing interval of 40 minutes. This is not a very satisfactory method as it does not allow for possible concentrations of animals in layers not included in the hauls. It does serve to indicate wide differences in abundance, however, and has been used in this manner to supplement the more accurate results which added facilities made possible during the second season. Beginning with cruise 26 on April 15, 1932, volumes were based on oblique tows and represent a metre net haul of 40 minutes duration through the total column of water. For vertical differences in distribution each haul was made in two parts, the first from the bottom to 50 metres and the second from 50 metres to the surface.

APRIL TO SEPTEMBER

Bigelow (1926, pp. 82-83) found that in 1920 the animal plankton of the gulf as a whole was at its lowest ebb in late February and during the first half of March. Later in March propagation began in Massachusetts bay and gradually spread seaward and to the east. General augmentation he found evident in April across the southern half of the gulf from the mouth of Massachusetts bay to the coastal bank off cape Sable, and including the eastern part of Georges bank. North of a line from cape Cod to cape Sable the records for 1920 indicated no increase, and in the northeastern part of the basin an unmistakable decrease in the amount of zooplankton took place from March to April coincident with the local flowering of diatoms.

It was at this season (April 15 to May 2) that investigations in the gulf of Maine began in 1932. Vernal propagation was taking place over a considerable portion of the gulf (Fish 1936a, fig. 5; 1936b, fig. 5) but its influence upon the adult population was as yet restricted to a very limited area. Elsewhere volumes were for the most part at the winter minimum. The mean volume for the total region included in the investigations was at this time 86 cc., that of the gulf of Maine 110 cc. and the bay of Fundy 62 cc. The latter area extended as far east as cape Spencer. Beyond this point in the headwaters of the bay eight hauls taken by the Nova IV (sta. 170-177) in April yielded a mean volume of only 29 cc.

The quantitative distribution of animal plankton in April is shown in figure 15. Vernal augmentation was particularly suggested in the most western line of stations in the gulf where the greatest volume, 870 cc., was obtained at station 26. Here 715 cc. of the total amount occurred in the upper 50 metres with juvenile *Calanus finmarchicus* comprising 42 per cent of the population. Young of this species also formed 37 per cent of the lower haul from 125 to 50 metres. (Species percentages indicate relative numerical values and not relative volumes.) It is in the upper 50 metres (fig. 15), where juvenile stages occur in greatest abundance, that the influence of recent propagation would be expected to be most readily detectable. Due, however, to the small parent stock remaining in both the gulf

and bay of Fundy, hauls through the total column of water indicated these conditions equally well.

It would appear that in 1932 the reproduction season began somewhat earlier than in 1920, and the line marking the limit of general augmentation of the adult population had by the end of April moved eastward to the vicinity of Casco bay.

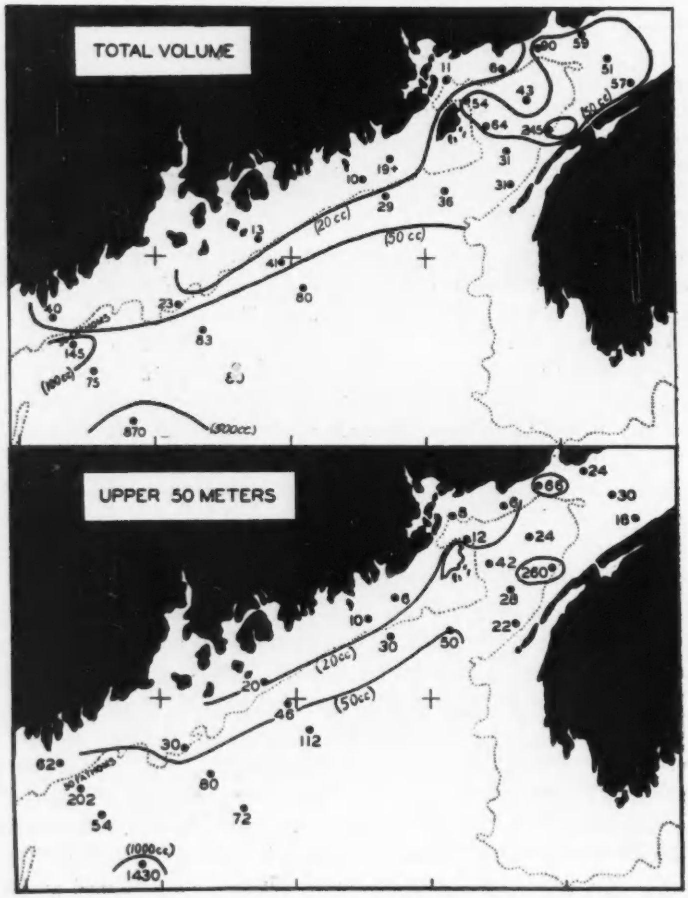


FIGURE 15. Quantitative distribution of zooplankton in April, 1932. Volumes measured by the displacement method.

North of a line from Casco bay to cape Sable the volumes were uniformly low and ranged from 6 cc. to 90 cc. with the exception of one station (37) on the Nova Scotian side of the bay of Fundy where a local swarm of large adult *Sagitta elegans* (probably from the outer part of the gulf of Maine, Bigelow 1926, p. 41) comprising 49 per cent of the haul yielded a volume of 155 cc. The most barren

area, with volumes ranging from 6 cc. to 19 cc., extended along the coast from the vicinity of cape Spencer to Penobscot bay. Throughout the summer this region contained the smallest adult population and showed the least influence of propagation as indicated by the presence of eggs, larvae and juvenile adults. The western boundary of the barren area varied during the season from Penobscot bay to Petit Manan, but more commonly it was found to terminate in the vicinity of Mount Desert. Bigelow (1926, p. 83) observed that the coastal area east of Penobscot bay was similarly barren in April, 1915.

As the dominant members of the zooplankton population, including *Calanus finmarchicus, Pseudocalanus minutus* and all four local species of *Thysanoessa,* begin reproducing in March and April and are soon followed by another important form, *Meganyctiphanes norvegica,* it was to be expected that metre net collections would show rapid restocking by late juveniles in May. The mean volume for the total region during the period May 19-31, 1932, was found to be 385 cc., an increase of 348 per cent over the previous month. This increase affected both the gulf of Maine and the bay of Fundy where the mean volumes amounted to 497 cc. (351 per cent increase) and 274 cc. (342 per cent increase) respectively. The richest zone continued to be centred in the western part of the gulf but the boundary had advanced northward to include the outer stations of sections to the east, and stations extending into the bay of Fundy along the Nova Scotia side (fig. 16). Station 37 again yielded a large haul, in fact the greatest volume taken on the cruise, but vernal augmentation now accounted for the size of the catch. In the upper haul juvenile *C. finmarchicus* formed 69 per cent and in the lower 53 per cent of the population. *Sagitta elegans* still formed 20 per cent of the lower haul but had declined considerably from the previous month. Comparatively rich hauls were regularly taken in the central deep portion of the bay and will be discussed later (p. 231).

The New Brunswick-eastern Maine coastal area still yielded the smallest volumes, the Quoddy region having increased only from 11 cc. to 20 cc. during the month, and in the vicinity of Saint John the quantities actually declined at sta. 11 and 12, the latter from 90 cc. to 31 cc. A similar condition was found in May, 1915, by Bigelow (1926, p. 83) who reported an increase by the end of the month throughout the gulf outside of the 50 metre contour with the exception of the coastal zone eastward of Penobscot bay. The relative distribution of high plankton volumes figured by Bigelow (1917, p. 313) was also markedly similar to that of 1932. The western boundary of the very barren area in 1932, due to the more advanced season, had by the end of May contracted eastward to the vicinity of Petit Manan. The peak of the season in the gulf was reached in May and thereafter a gradual decline took place throughout the following months. This also accords closely with the observations of Bigelow, who found the greatest mass of animal plankton during the last week in May and the first of June. By the end of June in 1932 the volume for the total region had declined to 299 cc., a decrease of 22 per cent. The decrease was most noticeable in the gulf (fig. 16) where the mean volume declined 38 per cent, *i.e.* to 308 cc.

In the bay of Fundy where the seasonal response was slower, the mean volume continued to increase slowly (6 per cent to 290 cc.) after the decline had set in in the gulf. The peak here was reached in June with the largest volumes occurring along the Nova Scotian side of the bay.

Although juveniles were more generally distributed throughout the total area

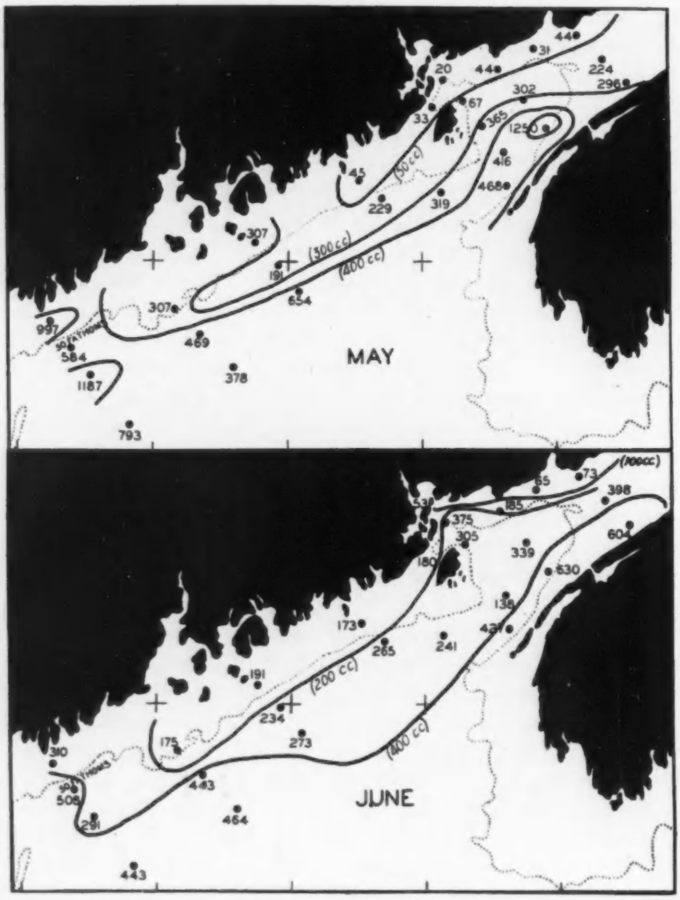


FIGURE 16 (part)

at this time, the relative quantitative distribution was strikingly similar to that of the previous two months. Sta. 37 again yielded the greatest quantity (*C. finmarchicus* and *P. minutus* forming 91 per cent in the upper haul and 85 per cent in the lower), and the New Brunswick-eastern Maine coastal area the smallest. The influence of restocking was everywhere evident in the latter area except in the vicinity of Saint John where the volume at sta. 12 was still below that of April.

As the June cruise terminated on July 1 an interval of five weeks was allowed before beginning the next on August 8. By this time a further reduction of 29 per cent to 213 cc., had taken place in the total area. The most rapid decline was now found in the bay of Fundy (42 per cent) and was remarkably similar to that of the gulf during the previous month (38 per cent). The rate of reduction

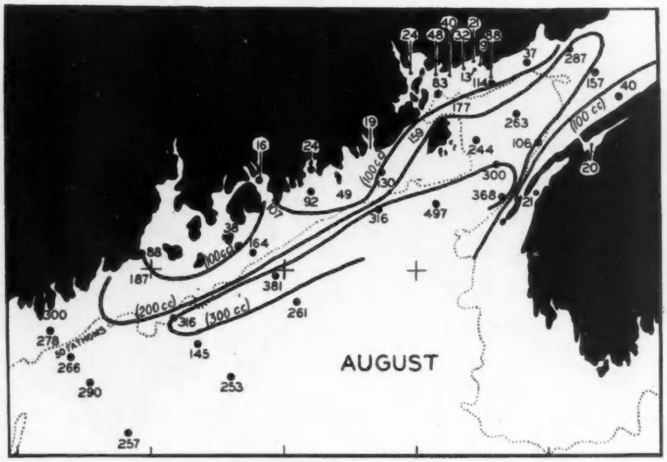


FIGURE 16 (con.). Quantitative distribution of zooplankton in May, June and August, 1932. Total volumes (displacement).

of the stock in the gulf appeared to have become slower, the mean volume of 257 cc. being but 17 per cent lower than that of late June.

The quantitative distribution of animal plankton now indicated a changing centre of abundance. During April, May and June the southwestern portion of the gulf had first increased in volume and later expanded to the east and into the bay of Fundy along the Nova Scotian shore. By August the volumes in the southwestern area had declined to amounts approximating those of the central portion of the bay of Fundy. The relatively barren New Brunswick-eastern Maine coastal area still persisted, but the richest hauls indicated by the 300 cc. curve (fig. 16) were now centred in a belt whose inner margin paralled the 50-fathom contour and extended from off Penobscot bay diagonally across the entrance of the bay of Fundy to the vicinity of the Boar's Head, Nova Scotia. A similarly rich belt, but broader and extending to Massachusetts bay, was found by Bigelow (1917, p. 308; 1926, p. 84) in 1913, 1914 and 1915, and is considered to be a typical summer condition, after the decline of the cold Nova Scotian drift described on pp. 195 and 312.

A continued decline in the adult stock of 27 per cent (155 cc.) took place over the total region in September. At this time the mean volume in the bay of Fundy had fallen to 119 cc. (–30 per cent) and in the gulf of Maine 198 cc. (–23 per cent). The stations in the latter area were too widely separated on the

September cruise to permit the drawing of detailed contours, but the conditions in the bay of Fundy indicated a quantitative distribution similar to that of August.

It was not possible to include on the routine cruises two areas reported by Bigelow (1917, p. 308) to be rich in summer, over the northeastern portion of Georges bank and from cape Sable out to Browns bank. The range was extended on a special cruise in September, 1932, and one station taken in each of these areas. Sta. A 1410, west of cape Sable, yielded a relatively high volume of 387

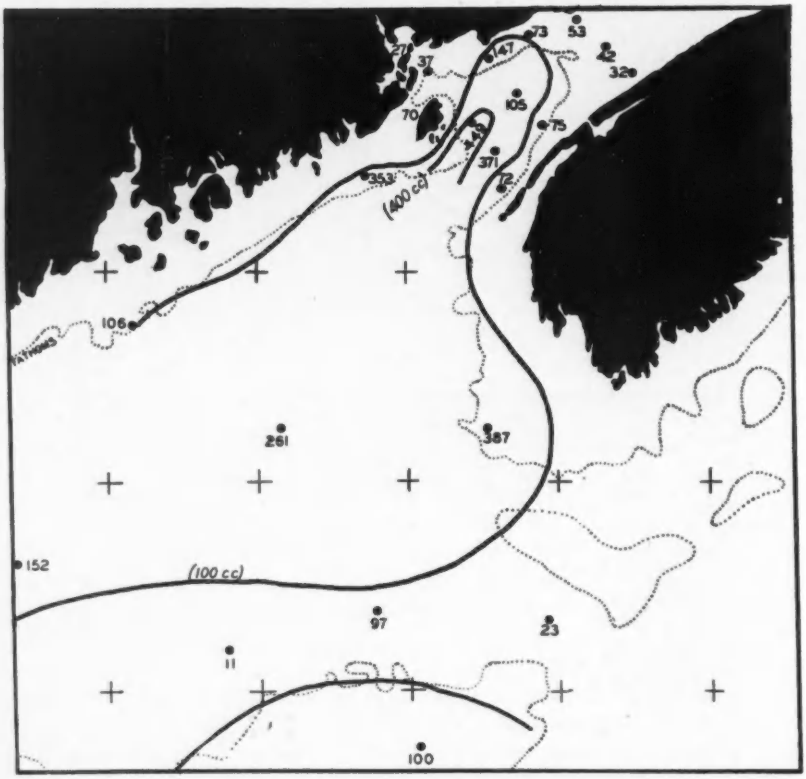


FIGURE 17. Quantitative distribution of zooplankton in September, 1932. Total volumes (displacement).

cc., suggesting that conditions in 1932 were here similar to those in 1914. At sta. A 1414 on the northeastern portion of Georges bank a volume of 100 cc. was obtained. This is relatively small contrasted with the other area and also with two stations taken farther west over the central portion of the bank. There at sta. A 1415 the volume was 440 cc. and at sta. A 1416, 248 cc. (*Centropages typicus* population).

Repeated high volumes taken at sta. 35, 36, and 37 in the bay of Fundy sug-

gest that the central area may form a vortex where zooplankton tends to temporarily accumulate due to the nature of the circulation about the bay. Again it is probable that the volumes over much of the bay are larger than might be expected because this area forms a sort of funnel, small in size when contrasted with the gulf. Animals entering the bay in the surface drift as regularly and constantly as drift bottles indicate would tend to be more concentrated there. This is merely mentioned as a point to bear in mind in comparing volumes in the two areas.

Sufficient data are not available to permit a satisfactory comparison of the quantities of animal plankton in 1931 and 1932. It was possible to take but one cruise in the bay of Fundy and gulf of Maine during the first season, and as the stations in the latter area were located nearer the coast than in the following year

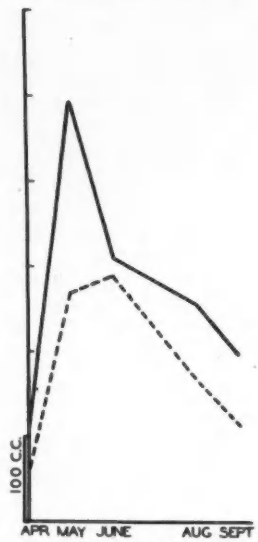


FIGURE 18. Variation in the mean volume (displacement) of zooplankton in the gulf of Maine and bay of Fundy during the principal period of augmentation in 1932.

they are not considered comparable. The mean of three gulf stations taken in both years (15, 17, 25-25A) amounted to 519 cc. in August 1931, and 945 cc. in August 1932. This small number of stations scattered over such a wide area is not sufficient to overcome differences due to local irregularities in distribution, and these figures are of significance only in that they indicate that the plankton in the gulf was far greater than in the bay during the two summer seasons. In the bay of Fundy the stations in September covered the same area and, although more observations were made in 1932, the mean volume indicates approximately the same amount of zooplankton present at that time in both years.

Year	Date	Mean volume (settling)
1931	September 1- 5	350 cc.
1932	September 14-26	335 cc.

TABLE III. Volume of zooplankton. Oblique metre net hauls adjusted to 40 minutes. Measurements by displacement method

Cruise	Date	Total area			Gulf of Maine			Bay of Fundy		
	1932	Mean volume cc.	Factor	% change	Mean volume cc.	Factor	% change	Mean volume cc.	Factor	% change
Bottom to surface										
26	Apr. 15-May 2	86	1		110	1		62	1	
27	May 19-May 31	385	4.5	348	497	4.5	351	274	4.4	342
28	June 20-July 1	299	3.5	−22	308	2.8	−38	290	4.7	6
30	Aug. 8-Aug. 21	213	2.5	−29	257	2.3	−17	169	2.7	−42
32	Sept. 14-Sept. 26	155	1.8	−27	198	1.8	−23	119	1.9	−30
Fifty metres to surface										
26	Apr. 15-May 2	102	1		158	1		46	1	
27	May 19-May 31	544	5.3	433	718	4.5	354	368	8	722
28	June 20-July 1	300	2.9	−45	300	1.9	−58	302	6.5	−18
30	Aug. 8-Aug. 21	222	2.1	−26	284	1.8	−5	160	3.5	−47
32	Sept. 14-Sept. 26							152	3.3	−5

Factor indicates the ratio to April volume.
Percentage change refers to preceding month.

Reviewing conditions throughout the summer season in 1932, with the beginning of vernal augmentation in March and April the zooplankton stock rose

rapidly from a winter minimum as low as 11 cc. in New Brunswick waters. As shown in figure 17, the mean volume over the total area increased 348 per cent from April to May. Reaching a peak in the gulf in late May and a month later in the bay, a summer decline followed, in spite of subsequent propagation, until by the end of September the stock had decreased 60 per cent in the gulf and 59 per cent in the bay of Fundy. At all times the quantity of zooplankton in the gulf was larger than in the bay, although the relative seasonal fluctuations in volume (fig. 18) and general nature of the community were very much the same.

Observations in the gulf terminated before the autumnal augmentation which precedes the long winter decline to the yearly minimum, but these changes are indicated in the following records obtained in the bay of Fundy during the winter of 1931-32.

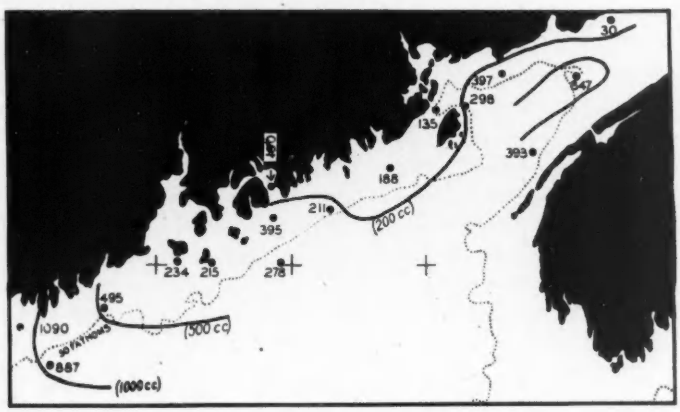


FIGURE 19. Quantitative distribution of zooplankton in August-September, 1931. Total volumes (settling).

WINTER CONDITIONS

Following the termination of the summer investigations in September, 1931, routine observations were continued through the winter at three stations in the bay of Fundy. Figure 20 gives the mean volume for September, November and December at two stations on a line across the entrance to the bay just east of Grand Manan. Sta. 8A was selected to indicate the population entering from the gulf of Maine, and sta. 6 that passing out along the east side of Grand Manan after circling the bay.

The decline in volume continued during October and early November at both stations, although the character of the population throughout the bay of Fundy, particularly in the upper level, was changing due to late fall augmentation of *Centropages typicus*. Copepodites of this species were taken in increasing abundance in August and by September formed an appreciable part of the population (pp. 306-307). Their numbers, however, were insufficient to conteract the de-

cline of other species until late November when the volume (settling) at sta. 8A rose rapidly from 279 cc. to 1160 cc. Judging from summer conditions the changes at this station would more closely approximate those in the gulf than in the bay of Fundy proper, although the response would be expected to be at least a month later than in the western area.

Support for this opinion is found in Bigelow's (1926, p. 87) records, "Vertical hauls in the Massachusetts Bay Region, the only part of the Gulf where our data warrant even a tentative account of the quantitative fluctuations that take place during late summer and autumn, suggest a diminution in the volume of zoo-

FIGURE 20. Seasonal variation in the volume of zooplankton at stations 6 and 8A in the bay of Fundy during the periods, September-December, 1931, and March-September, 1932. Average monthly volumes (settling).

plankton during the late summer followed by an autumnal increase, which was so considerable in 1915 that there was over twice as much plankton per square metre in water only 80 metres deep by the end of October as we had found at a neighbouring station in 140 metres depth two months previous."

If sta. 6 be considered characteristic of the bay of Fundy and sta. 8A as indicative of the adjacent part of the gulf of Maine, the volume within the bay was greater than the eastern gulf area from September to November but the rate of decline was approximately the same. The rapid rise in late November was most

marked at sta. 8A where an increase of 316 per cent took place. At sta. 6 the response was slower and by December amounted to only 50 per cent. Due to a fire, samples taken in January and February were destroyed and whether or not the December records represented the winter maximum in the bay could not be determined, but by March volumes had declined to 74 cc. at sta. 6 and 105 cc. at sta. 8A.

In the annual cycle of quantitative changes, the great vernal increase followed almost immediately by a sharp decline, amounting to 38 per cent in the gulf in June and 42 per cent in the bay a month later, is most striking. The period of augmentation, reflecting propagation by the dominant boreal species (p. 306), is easily understandable, but the reason for the rapid depletion may be open to question. Several possible contributing causes suggest themselves, among which are: (1) high mortality in the dominant copepod stock during maturation (p. 316) and after spawning (Bigelow 1926, p. 43); (2) dispersal from propagation centres to relatively less productive areas resulting in more even distribution of the stock; (3) animals upon reaching maturity descending to the bottom in shallow areas and to depths beyond the range of the haul in deeper areas; (4) euphausiids in later stages avoiding the nets.

1. In light of all available evidence it seems most probable that the great decline following the May-June peak is due to normal biological factors involving primarily the dominant boreal copepods. As the fluctuations in the total volume reflect to a large extent changes in the content of the most important species, *Calanus finmarchicus*, forming 35 to 40 per cent of the total zooplankton population (Fish 1936a, p. 120) in the region, the rapid downward trend in June coincides with the critical period of maturation (p. 319) combined with the subsequent mortality of adults after spawning.

Pseudocalanus minutus, forming from 5 to 10 per cent of the population (Fish 1936b, p. 213) and second in importance, also passes through a very similar cycle at approximately the same time. Biological changes in these two species alone would thus affect up to 50 per cent of the total zooplankton stock in the region.

2. Regarding dispersal, assuming that one area is unproductive and depends upon immigration from another area for its population, one would expect the response in the unproductive area to any changes in the productive area to be delayed, the time interval depending on the distance involved. Applying these considerations to the gulf of Maine and the bay of Fundy, it was found that in 1932 the May increase in the gulf was continued in the bay through June. A decline of 38 per cent in the gulf in June was followed by a drop of 42 per cent in the bay in July and early August. Similarly the seasonal reduction of 60 per cent in the gulf was reflected in the bay by a decline of 59 per cent. The decline in the former area extended over a period of four months, but once the supply was reduced a decline of like degree took place in the bay of Fundy in three months.

Were it not for other data indicating the lack of successful production in the bay of Fundy, these figures would not in themselves be conclusive because they

could be interpreted as indicating production on a smaller scale taking place later in the bay of Fundy. The close accordance of the relative fluctuations in the two areas, however, and the fact that the quantity of zooplankton in the gulf was at all times so great that it governed the mean volume for the total region throughout the season, suggests the product of that area as the dominant influencing factor.

Further evidence that the fluctuations in the bay of Fundy result from importation, and not delayed response due to differences in latitude, is indicated in figure 20 contrasting two stations within the bay itself. These stations were located only 30 miles apart (fig. 2), a distance hardly sufficient to allow for seasonal differences in local production. At sta. 8A this response followed closely

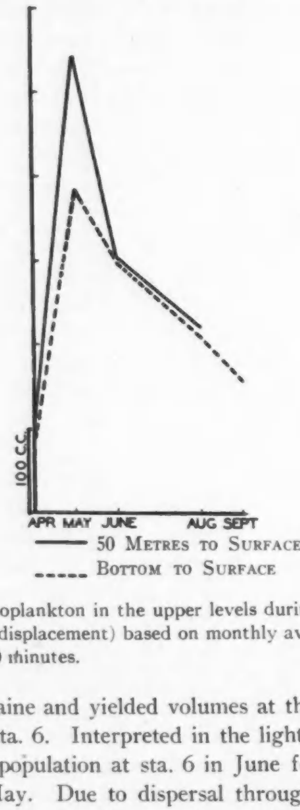


Figure 21. Abundance of zooplankton in the upper levels during the augmentation season in 1932. Mean volumes (displacement) based on monthly averages of all stations, adjusted to a towing period of 40 minutes.

changes in the gulf of Maine and yielded volumes at the peak of the season considerably higher than at sta. 6. Interpreted in the light of hydrographic evidence it would appear that the population at sta. 6 in June formed a part of the stock observed at sta. 8A in May. Due to dispersal throughout the bay, the volume, provided no significant local production supplemented the immigrant stock, would be expected to be smaller at sta. 6, as proved to be the case. There would thus appear to be little doubt that the stock in rich areas of the gulf is diluted by dispersal into less productive waters, but this takes place gradually and continuously throughout the summer. It is probably at best only a minor contributing factor in the sudden June depletion.

3. Animals immediately adjacent to the bottom would not be taken in an oblique haul made in the usual manner. In the present investigations the nets traversed as nearly as possible the total column of water at most stations and to depths exceeding 150 metres at the few deeper stations in the gulf. As the dominant species of *Calanus, Pseudocalanus,* and *Meganyctiphanes* in summer have been found to have their centre of abundance in the upper 100 metres (Bigelow 1926) and the present records (fig. 21) indicate that within this range the quantities in the upper 50 metres throughout the spring and summer season exceeded those below, it seems probable that the samples were representative and the decline shown in the volume curve indicated a corresponding reduction in the actual amount of animal plankton.

4. In regard to the euphausiids, the greater part of those hatched in April might not be included in the hauls after June or early July, but they would comprise largely species of *Thysanoessa* which in the region were found both as adults and young in much smaller numbers than *M. norvegica.* The latter species reached its maximum production in July and August when, even with the greatly reduced stock at the time, it did not exert any detectable influence on the declining volume curve. It would therefore appear that the absence in the net hauls of juveniles of the less abundant species would probably prove of equally minor significance, and that the first suggested cause (p. 229) is the most probable.

The downward trend of zooplankton volumes throughout the summer was rather unexpected, for all dominant spring spawning species, with the exception of *Thysanoessa,* had at least one subsequent breeding season, and that of *M. norvegica* reached its peak in July and August. Again the available parent stock in June and July was much greater than that at the beginning of the season in March. The volumes, however, show clearly that the influence of summer spawning by young adults is relatively small compared with that of the older stock in the spring. The possible cause for this will be considered later (pp. 316-317).

Composition of the Zooplankton Population

Boreal waters, contrasted with more temperate and tropical regions, are comparatively rich in individuals but notoriously sparse in the number of species comprising the zooplankton population. The contrast is further accentuated by the fact that, out of the total local population, only a relatively small number of endemic species comprise the greater part of the stock at all times. Of more than 160 species occurring in the net collections in the gulf of Maine, three or four usually account for more than 80 per cent of the total number of individuals, and frequently this percentage is much larger.

The present chapter will be devoted to a consideration of the relative composition of the total zooplankton population. In analyzing this population, particularly from the standpoint of natural economy, an attempt has been made to first determine the relative numerical importance of the various ecological groups represented. Detailed analyses of the distribution and biology of dominant in-

dividual species of the offshore stock in the region have been published elsewhere (Huntsman and Reid 1921, Bigelow 1926, Fish 1936a, 1936b and c).

Within the gulf of Maine and bay of Fundy the zooplankton stock during the course of the year is composed of the following groups: boreal endemic species, northern and southern migrants, neritic plankton species, fish eggs and larvae, larvae of benthonic invertebrates, and occasional adult benthonic invertebrates. The relative importance of the groups varies geographically and also with the seasons.

If considered only from the standpoint of natural economy, some of these groups might have been omitted entirely in the present report. However, since this forms the first attempt to determine the relative composition of the complete zooplankton stock in the region, we feel it desirable to include a comparable analysis of all groups represented even though some of the data are not applicable to the immediate problem. Only in this way can a clear conception of the population as a whole be obtained. Again anyone interested solely in the Quoddy region (p. 190) may disregard the remainder of this chapter.

TABLE IV. Composition of the zooplankton population in the bay of Fundy.

						1931
Month	July	Aug.	Sept.	Oct.	Nov.	Dec.
Number of hauls	3	6	14	4	9	12
Endemic boreal species	91.8	89.3	93.0	98.7	99.1	99.1
Northern immigrants	.3	.7	.04	.3	.4	.3
Southern immigrants			.04		.1	T
Neritic zooplankton	5.5	9.4	2.0	.7	T	.04
Fish eggs and larvae	3.1	.2	1.5	T	T	T
Benthonic invertebrate larvae	T	T	3.2	T	T	T
Benthonic invertebrates	T	T	T			
						1917
Month	Jan.	Feb.	Apr.	May	June	July
Number of hauls	1	3	2	2	2	4
Endemic boreal species	99.0	96.6	92.3	98.1	86.3	96.5
Northern immigrants	1.0	3.3	1.9	1.1	13.8	2.9
Southern immigrants						
Neritic zooplankton			2.4	T		
Fish eggs and larvae			1.5			
Benthonic invertebrate larvae			1.9	.8		.6
Benthonic invertebrates						

RELATIVE NUMERICAL IMPORTANCE OF THE ECOLOGICAL GROUPS

Bay of Fundy. Observations were continued throughout the year only in the bay of Fundy, where of the seven groups, boreal endemic forms were found to constitute more than 80 per cent at all times, and for the greater part of the year ranged from 90 per cent to 99 per cent. Since the mean for all stations for the year October 1931 to September 1932 was 94.4 per cent, and for the period from January to December 1917 was 96.5 per cent, it would appear that the boreal group may be expected to average about 95 per cent of the total zooplankton population in the bay. Larvae of benthonic invertebrates ranked second in 1931-32 with a yearly mean of 2.9 per cent and neritic plankton species third with 1.9 per cent.

Comparing the results for the period from July to September in 1931 and 1932 in the bay, it is seen that the composition of the population was substantially the same in the two years:

	1931	1932
Endemic boreal species	91.4	92.1
Northern immigrants	.3	.4
Southern immigrants	.01	.03
Neritic species (plankton)	5.6	5.9
Fish eggs and larvae	1.6	.3
Benthonic invertebrate larvae	1.1	1.4
Benthonic invertebrates	T	T

Inner gulf. Inasmuch as the bay and adjacent portion of the inner gulf (central area) have been shown to be relatively barren as contrasted with the region west of Mount Desert, (p. 220) it is of importance to consider the composition of their respective populations, during the period from April to September, which

Relative percentages of the various ecological groups in metre net collections.

1932								
Jan.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.-Sept.
2	6	25	25	25	2	26	24	160
98.9	98.2	81.0	90.2	96.4	99.8	85.1	91.7	94.4
T	.6	.5	.1	.2	.2	T	.2	.3
	.2	T	T	.1	.1	T	T	.1
.7	.3	.2	.5	.6	.1	11.6	6.0	1.9
.2	T	.4	1.1	1.2	T	.2	.6	.3
	.4	17.6	8.1	1.2	.1	3.3	1.5	2.9
		.3	T	.2	T	T	T	.1

Sept.	Oct.	Nov.	Dec.		Jan.-Dec.
3	2	1	2		22
99.8	99.3	99.6	98.1		96.5
T	.4		2.0		2.7
		T			T
		T			.2
					.2
	.3	.4			.4

forms the principal augmentation season of open gulf species and also the time when neritic plankton species and benthonic larvae reach their peak. That this barrenness results from lack of successful propagation of open gulf species is indicated by the fact that even in the reduced population the relative percentage of this group becomes increasingly smaller to the eastward. Whereas endemic boreal species totalled 97.6 per cent in the western area, in the central area they amounted to 89.3 per cent and in the bay 88.9 per cent (table V).

Benthonic larvae, however, do not appear to be influenced to the same degree as offshore planktonic species by limiting factors and develop successfully throughout the region. Thus although the actual numbers of individuals in all groups are larger in the western gulf, the relative percentages of benthonic larvae (9.2

per cent, central area; 6.3 per cent, bay) are higher in the eastern gulf and bay.

The remaining four groups totalled 0.7 per cent in the western area, 0.8 per cent in the central area, and 1.0 per cent in the bay.

Outer gulf. Bigelow's records (1926, pp. 47-50) indicate that from late autumn until March the zooplankton is fairly uniform over a greater part of the gulf and consists largely of boreal species. However, during the period from

TABLE V. Composition of the zooplankton population from April to September,

Area	Total region						Western area		
Month	Apr.	May	June	Aug.	Sept.	Apr.-Sept.	Apr.	May	June
Cruise	26	27	28	30	32		26	27	28
Endemic boreal species	78.5	93.9	97.5	92.3	97.2	91.9	95.1	99.4	96.7
Northern migrants	.3	.2	.1	.01	.07	.13	.3	.05	.1
Southern migrants	.04	.01	.05	.1	T	.05	.02	.02	T
Neritic species	.1	.3	.6	5.3	2.0	1.7	T	.2	1.0
Fish eggs and larvae	.5	.6	1.2	.8	.2	.6	.3	.03	1.3
Benthonic ivertebrate larvae	20.5	4.8	.5	1.3	.5	5.5	4.4	.3	.3
Benthonic invertebrates	.1	T	.07	T	T	.03			

April to September local production, particularly of neritic species and larval benthonic forms, would be expected to influence significantly the population of the inner gulf, and perhaps through the agency of the drift extend well out into offshore waters, particularly in the upper levels.

To determine how much more coastal conditions influence the composition of the population of the inner gulf than the offshore basin, hauls from the bottom to 50 metres at the three outermost stations (26, 29, and 31) were selected. These stations were located in the inner part of the basin where depths exceed 175 metres, and are considered generally indicative of offshore conditions. Taking the mean for the three stations on four cruises between April and August, and one station

TABLE VI. Composition of the zooplankton in different areas in May and

Year	1932			
Month	May			
Period	19-24	18-19	18	14
Area	Off Cape Ann	Western basin	Central basin	Eastern channel
Stations	N260-261	N258-259	N255-256	N245
Endemic boreal species	99.2	99.8	99.6	97.5
Northern migrants				T
Southern migrants	T	T	T	T
Neritic species	.6	.2		
Fish eggs and larvae	.2			1.5
Larvae of benthonic invertebrates	T		T	1.0
Benthonic invertebrates				

in the middle of the gulf (A1411) in September, the following values were obtained: endemic boreal species 98.8 per cent, northern immigrants 0.4 per cent, southern immigrants 0.1 per cent, other forms combined 0.7 per cent. At no time during the summer did the percentage of endemic boreal species fall below 98.2 per cent (June) and in August the percentage reached 99.7 per cent.

To these data may be added the following offshore records for May and September, 1932. It will be noted that the boreal population exceeded 90 per cent everywhere except in the bay of Fundy for a brief period in late May when *Balanus balanoides* larvae swarmed in those waters. Then the percentage declined from 90.2 per cent (May 18-23) to 72.7 per cent (May 30-June 2) but quickly rose again to 96.4 per cent by June 20 (table VI).

1932. Relative percentages of the various ecological groups in metre net collections

		Central area					Bay of Fundy				
Aug.	Sept.	Apr.	May	June	Aug.	Sept.	Apr.	May	June	Aug.	Sept.
30	32	26	27	28	30	32	26	27	28	30	32
96.9	99.8	59.2	92.1	99.5	95.1	100.0	81.0	90.2	96.4	85.1	91.7
T	T	.1	.3	.05	.04	T	.5	.1	.2	T	.2
.1	T	.1	T	.05	.3	T	T	T'	.1	T	T
1.3	T	.1	.1	.1	3.1		.2	.5	.6	11.6	6.0
1.2		.9	.8	.2	1.0	T	.4	1.1	1.2	.2	.6
.1	T	39.6	6.0	.1	.5	T	17.6	8.1	1.2	3.3	1.5
T	T	T	T		T		.3	T	.2	T	T

It would thus appear that west of Mount Desert, even during the summer, endemic boreal species of the offshore population form substantially as important a part of the stock in coastal waters outside of the headlands as anywhere in the open gulf, and that in the eastern coastal region and the bay of Fundy the influence of larvae of benthonic forms and neritic species probably average less than 10 per cent.

ENDEMIC POPULATION

This term should really apply to both boreal oceanic and boreal neritic species endemic in the region, but for purposes of distinction in the present report it will be considered to apply only to the offshore species characterizing the open gulf

September. Relative percentages of the various ecological groups in metre net collections

							1931
		September					
14	30-June 2	20-23	20-24	25	23	15-16	1-5
Brown's bank	Bay of Fundy	Inner gulf	Outer gulf	Georges bank	W. coast Nova Scotia	Bay of Fundy	
N244	N273-284						
100.0	72.7	100.0	94.0	97.2	99.7	91.7	93.0
	.4	T	.6		T	.2	.04
		T	4.5	2.3	.3	T	.04
	.5	T	T			6.0	2.0
T	.2	T	T	T		.6	1.5
	26.2	T	.9	.3		1.5	3.2
	T	T		.2		T	T

community. Plankton species associated with the coast and restricted largely to relatively shallow waters will be designated as neritic.

Number of species. The boreal population includes approximately 30 species universal in the gulf and bay of Fundy. Twenty-seven of these, listed in table VII, occurred regularly at some time during the year in the metre nets, and two

additional small species, *Oithona similis* and *Microsetella norvegica,* appeared in the pump samples. A few other species, particularly copepods, of which Bigelow lists three, *Paracalanus parvus, Candacia norvegica* and *Monstrilla serricornis,* have been reported. The exact status of the two latter species is uncertain as they have as yet been found only in small numbers in Norwegian waters and the gulf of Maine. *Paracalanus* at times is widespread in the gulf (Bigelow 1926, p. 264) and the presence of a few larvae in 1932 indicates that it propagates there during the summer, but for reasons which will be discussed later (p. 250), it is considered a more temperate species in the western Atlantic, centred south of cape Cod. No specimens were taken in the net collections in either 1931 or 1932. Considering the number of observations which have been made in the gulf and bay of Fundy, it is not probable that other truly boreal species which may at times enter the region, but have escaped detection, ever prove numerically significant.

Bigelow (1926, p. 16) has previously called attention to the qualitative uniformity of the zooplankton in the open gulf throughout the year, and lists as the typical "Calanus community", *Calanus finmarchicus, Pseudocalanus minutus, Metridia lucens, Sagitta elegans, Euthemisto,* the several species of *Thysanoessa, Meganyctiphanes norvegica, Limacina retroversa, Pleurobrachia pileus,* and in deeper water *Euchaeta norvegica.* These form the most common members of the endemic group, and may be expected in collections everywhere in the open gulf at any season. (See pp. 309-310 for discussion of status of *M. lucens.* Because of the seasonal and geographical range of the adult stock it is here grouped with endemic species.)

Seasonal variation. Quantitatively, however, the composition of the population varies greatly at different times of the year and in different areas. All observed endemic forms have definite propagation periods and it is then that the relative importance of the particular species breeding at the time is usually greatest. Considered on the basis of seasonal changes, the boreal population falls into three general classes:

(1) A relatively few species such as *Centropages typicus* and *Anomalocera patersoni* all but disappear shortly after the termination of the augmentation period and occur only sparsely, if at all, within the region until the next breeding season.

(2) Other species like *Euthemisto compressa* and *Temora longicornis* are nearly always present in the gulf but, in the inner coastal region at least, appear to be of numerical significance for only a limited portion of the year.

(3) A third class, of which the copepods *Calanus, Metridia,* and *Pseudocalanus* are most important, are at all times abundant somewhere in the region, and except for a short time in autumn when *Centropages typicus* swarms in the upper levels, make up the bulk of the population over the greater part of the gulf and bay throughout the year. In the bay of Fundy in 1931-1932 these three species formed 56.3 per cent (by number) in the metre net collections, and in 1917 when *Centropages* did not swarm, they averaged 90.1 per cent.

Of the three classes it would appear that the greatest variation from year to

year occurs in the first, which most closely resembles the neritic group in being confined largely to the upper levels and almost totally absent for a part of the year. Even the most abundant member of this class, *Centropages typicus,* which swarmed in the autumn of 1931 and 1932 (p. 239) in the bay was apparently lacking at that season in 1917, appearing only in April with an average of 0.8 per cent for the month. Whether individuals of this class, like certain neritic species, pass a portion of the year in a resting stage, possibly in the form of eggs, is not known. Their restriction to the upper portion of the water mass would render them more exposed to unusual climatic conditions than the more typical boreal species with a wider vertical range. A proper allocation of *Centropages typicus* is further complicated by its seasonal distribution in different areas. South of cape Cod it occurs at Woods Hole as one of the dominant late summer and autumn species, and is commonly found at this time offshore as far south as Chesapeake bay (Bigelow 1926, p. 221). This, together with the fact that it has not been reported north of cape Sable, would tend to group it with the southern ranging Virginian fauna, were it not that propagation immediately south of cape Cod apparently takes place at minimum temperatures in January and February (Fish 1925, fig. 44) and, as a typically winter form in Chesapeake bay (Wilson 1932b, p. 23), it is probable that winter spawning occurs there also. Considering again its success in maintaining itself in the gulf of Maine where it usually reaches its peak at approximately the same time as at Woods Hole, it seems likely that *C. typicus* is really a boreal-temperate species which is more indifferent to high temperatures than the more typical boreal forms.

Regional variation. All boreal species vary considerably in abundance in different parts of the region. This is to be expected where variability in the productivity of different areas is so great. Certain species, particularly the dominant ones, may swarm over large areas, as in the case of *Calanus* in the western basin in summer. Bigelow (1926, p. 18) obtained six quarts of this species with many larval *Merluccius* and little else in a 15-minute metre net haul in the upper 40 metres off cape Cod on July 22, 1916. Again on June 26, 1934, a 15-minute oblique haul with a half-metre net of number 15 silk bolting cloth yielded one quart of *Calanus* with only an occasional *Limacina* offshore in the western basin. No such aggregations of this species were found in the inner gulf or bay of Fundy at any time in 1931 or 1932.

Strictly local swarms of individual species are also common. In some instances these concentrations occur regularly, particularly in the vicinity of offshore banks in summer, and are probably due to localized production on a relatively large scale. Bigelow has described repeated observations of concentrations of *Sagitta elegans* and *Temora longicornis* on Georges bank in July and August, and *Euthemisto* on Browns bank in midsummer (1926, pp. 21-22). In August, 1926, *Temora* again dominated in collections from the central portion of Georges bank, and on September 20, 1932, spawning adults of *Euthemisto compressa* formed 26.2 per cent of the haul at one station (A1400) off the inner edge of this bank

but did not exceed 2 per cent at any of five other stations in the same general area (fig. 22).

Except in the vicinity of restricted production centres, local swarms of endemic boreal species appear to result most commonly from a combination of environmental factors which make their location largely a matter of chance. Such concentrations are usually of limited duration and their location unpredictable. A local swarm of *Sagitta elegans* in the bay of Fundy, forming 42.9 per cent at sta. 9 and 33.8 per cent at sta. 10A on April 19, is an example of this type of swarm (fig. 23).

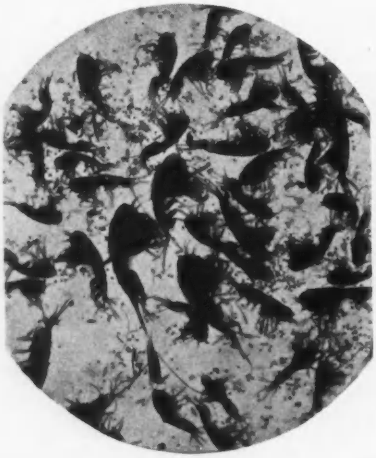


FIGURE 22. Zooplankton population dominated by *Euthemisto compressa* at station A1400 on September 20, 1932. Eggs and larvae, visible in figure, are from the brood pouches.

FIGURE 23. Zooplankton population dominated by *Sagitta elegans*. Bay of Fundy (station 9), April 19, 1932.

To cite another example, on May 24 *Oikopleura labradoriensis* formed 20 per cent of the population at sta. 33 in the central area, but less than 1 per cent at neighbouring stations on either side. Similar local swarms of this species were found at several other stations in the eastern gulf and bay at this time.

Certain species appear to be constant residents in some localities and distinctly seasonal in others. *Pleurobrachia pileus* was invariably found abundant by Bigelow (1926, p. 367) in the region of German bank and the shoals west of Nova Scotia, and the following records of its occurrence in 1932 at all stations in this locality affords added confirmation.

1932	Station	Percentage
Jan. 22	N 52	92.5
Jan. 22	N 54	27.8

1932	Station	Percentage
Jan. 23	N 55	87.8
Jan. 23	N 56	42.4
Jan. 25	N 58	71.9
April 20	N 190	70.7
April 24	N 200	66.6
April 24	N 201	92.5
May 14	N 244	4.8
Sept. 23	A 1410	5.7

Elsewhere this species appears to have a definite seasonal periodicity in its annual cycle as described on page 299.

Evaluation of species. In determining the relative numerical importance of individual species of the endemic boreal group, local irregularities in distribution have been overcome by taking the average of all stations in the area. Young stages when found in the metre net have been included in the calculations. Particularly in *Clione, Euthemisto,* and *Meganyctiphanes,* juveniles often comprised the greater part of the count.

With the exception of euphausiids the boreal population appears to have been effectively sampled. The fact that the largest numbers of *Meganyctiphanes norvegica* and the several species of *Thysanoessa* were regularly taken at night, however, indicates clearly that an appreciable part of this stock successfully avoided the nets during the daylight hours. The abundance of eggs during the breeding season affords further evidence of a richer population than our daytime captures would indicate. It should also be remembered in this regard that the present method of analysis deals solely with numerical importance. Euphausiids, because of their large size frequently formed the bulk of a sample even though outnumbered by several smaller species. They undoubtedly have a very important part in the natural economy of the region, and will be considered later in a separate publication.

Bay of Fundy. For the year October 1931 to September 1932 the following relative percentages (by number) were obtained. Records for *Oithona similis* and *Microsetella norvegica* are available only for the period April-September and will be considered later, p. 242.

Calanus finmarchicus	38.6	*Oikopleura labradoriensis*	0.5
Centropages typicus	22.6	*Thysanoessa sp. (juvenile)*	0.3
Pseudocalanus minutus	10.0	*Oithona plumifera*	0.2
Euphausiid eggs	8.9	*Limacina retroversa*	0.2
Metridia lucens	7.1	*Thysanoessa inermis*	0.1
Sagitta elegans	2.2	*Euthemisto compressa*	0.1
Tomopteris catherina	1.0	*Temora longicornis*	0.1
Stephanomia cara	1.0	*Halithalestris croni*	0.04
Meganyctiphanes norvegica	0.7	*Euchaeta norvegica*	0.04
Clione limacina	0.7	*Thysanoessa neglecta*	0.01

Thysanoessa raschii	0.01	*Euthemisto bispinosa*	T
Fritillaria borealis	0.01	*Hyperia galba*	T
Aglantha digitalis	0.01	*Pleurobrachia pileus*	T
Anomalocera patersoni	T	*Beroë cucumis*	T
Thysanoessa longicaudata	T		

The four most important boreal species in the bay, *Calanus, Centropages, Pseudocalanus,* and *Metridia,* comprised 78.3 per cent of the total zooplankton population in 1931-32, and in 1917, when the *Centropages* autumn crop apparently failed to develop (0.1 per cent), the percentage of the other three species was proportionately greater, amounting as previously stated (p. 236) to 90.1 per cent. Euphausiid eggs, although strictly seasonal, form a surprisingly large percentage, and may themselves prove a very important source of food for certain species.

In 1931 the average for all stations in August and September in the bay indicates that the same six boreal forms and those alone exceeded one per cent. The results for this period in the two years are listed below.

	1931	1932
Calanus finmarchicus	49.1	35.6
Centropages typicus	7.4	26.0
Metridia lucens	2.3	10.0
Pseudocalanus minutus	3.9	4.2
Meganyctiphanes norvegica eggs	28.6	8.7
Sagitta elegans	2.2	1.6
	93.5	86.1

TABLE VII. Occurrence of boreal zooplankton in

Area	Total region						Western area			
Month, 1932	Apr.	May	June	Aug.	Sept.	Apr.-Sept.	Apr.	May	June	Aug.
Cruise	26	27	28	30	32		26	27	28	30
Calanus finmarchicus	25.4	58.4	42.9	39.3	56.7	44.5	34.6	68.0	40.0	40.7
Metridia lucens	5.3	6.5	26.3	20.1	11.6	14.0	6.9	11.0	38.0	15.9
Pseudocalanus minutus	13.1	11.7	15.1	2.2	1.3	8.7	10.8	4.3	3.5	..5
Centropages typicus	T	.1	.1	10.3	25.9	7.3	T	.08	.3	10.9
Euphausiid egg	21.2	8.6	9.4	9.7	.2	9.8	33.1	5.9	10.6	8.3
Sagitta elegans	5.9	.8	.4	1.1	.5	1.7	.9	T	.3	.8
Meganyctiphanes norvegica	1.8	.9	.5	5.0	.02	1.6	1.6	2.3	.7	12.3
Oikopleura labradoriensis	.6	4.4	.6	.4		1.2	1.5	5.5	.5	.6
Limacina retroversa	.2	.07	.6	2.2	.4	.7	.3	.2	.7	4.7
Tomopteris catherina	2.0	.2	.03	.2	.03	.5	.2	.07	T	.5
Thysanoessa sp. (Juvenile)	.07	1.6	.8	.01	T	.5	.2	.8	.9	T
Stephanomia cara	.8	.2	.3	.5	.07	.4	1.6	.5	.4	.9
Clione limacina & young	1.3	.3	.03	.1	.03	.4	1.5	.02	.03	.1
Euchaeta norvegica	.3	.2	.01	.04	.3	.2	T	.7	.6	.04
Temora longicornis		.03	.02	.2	.2	.1			.06	
Fritillaria borealis	.5	.07	T	T		.1	1.9	.04	T	T
Aglantha digitalis	.04	.01	.03	.2	T	.06	.03	.02	.04	.3
Thysanoessa inermis	.2	T	T	.05	T	.05	.01	T	T	.04
Euthemisto compressa & young	T	.04	.01	.1	.1	.04	T	.02	T	.2
Anomalocera patersoni			T	.01	T	T			T	..02
Halithalestris croni	T	T	T			T	.01			
Euthemisto bispinosa	T				T	T				
Hyperia galba	T	T	T	T	T	T	T			
Thysanoessa longicaudata	T	T		T	T	T	T			
Thysanoessa neglecta	.02	T	T	T	T	T	T	T	T	T
Thysanoessa raschii	T	T	T		T	T	T		T	
Beroe cucumis	.02	T				T	T			
Pleurobrachia pileus	T	T		.05		.01				.1

Observations were made about two weeks later in 1932 than in the previous year, which would account for the greater augmentation of *Centropages typicus* and decrease in *Meganyctiphanes* eggs. Except for *Metridia lucens,* which was generally more abundant throughout the region in 1932 than at a comparable period in the late summer of 1931, the composition of the population would appear to have been substantially the same during the two years.

Total region. Comparing all areas, table VII indicates that members of the boreal group occurred throughout the region and in very much the same relative proportion in 1932.

During the period from April to September certain species, more restricted to offshore waters, were relatively less abundant in the turbulent eastern coastal area, thus increasing somewhat in those areas the relative importance of the more universal species. This is evident in the case of *Metridia lucens* where the mean decreased gradually from 19.4 per cent in the western gulf to 6.9 per cent in the bay while the percentage of *Pseudocalanus* increased to the eastward over the same range from 3.9 per cent to 16 per cent. However, when combined, the totals for the four dominant species were very similar, declining but slightly from 76.8 per cent west of Mount Desert to 74.1 per cent in the central area and 72.6 per cent in the bay. Considered by months, these four species totalled throughout the region 43.8 per cent in April, 76.7 per cent in May, 84.4 per cent in June, 71.9 per cent in August and 95.5 per cent in September, or 74.5 per cent for the season.

Averaged from the five cruises between April and September, forming the period of greatest divergence in the zooplankton, but seven boreal endemic species exceeded one per cent in the western gulf, and five in the other two areas. This

1932. Relative percentages in metre net collections

		Central area						Bay of Fundy					
Sept. 32	Apr. – Sept.	Apr. 26	May 27	June 28	Aug. 30	Sept. 32	Apr. – Sept.	Apr. 26	May 27	June 28	Aug. 30	Sept. 32	Apr. – Sept.
43.2	45.3	18.5	54.9	39.0	42.7	90.2	49.1	23.2	52.2	49.7	34.4	36.8	39.3
25.4	19.4	4.0	6.0	34.2	31.6	2.3	15.5	5.0	2.5	6.8	13.0	7.1	6.9
.3	3.9	5.2	12.5	11.8	1.4		6.2	23.2	18.4	30.1	4.7	3.6	16.0
29.7	8.2			.1	8.4	7.5	3.2			.02	11.6	40.4	10.4
T	11.6	27.2	11.9	11.3	4.0		10.9	3.4	8.1	6.2	16.8	.5	7.0
T	.4	1.0	.3	.4	.9	T	.5	15.9	2.0	.5	1.7	1.4	4.3
T	3.4	.03	.3	.4	1.8	T	0.5	3.8	.2	.4	.9	.05	1.0
	1.6	.2	4.7	.1	.4		1.1	.1	3.1	1.1	.1		.9
.3	1.2	.2	T	.6	2.6	T	.7	.1	.03	.6	.8	.7	.4
T	.2	.5	T	T	.1	T	.1	3.8	.3	.06	.1	.1	.9
T	.4	.04	1.2	.7	T	T	.3	T	2.3	.8	.03	T	.6
T	.7	.8	.05	.3	.4		.3	.3	.2	.1	.3	.02	.2
T	.3	.8	.03	.1	.06	T	.2	1.5	.5	T	.07	.1	.4
.7	.5	.6	.1	.07	.06	T	.2	.02	.1	.01	.02	.02	.03
.2	.05				.04		.01		.06	.01	.5	.5	.2
	.4	.1	.07	.4	T		.1	T	.08		T		.02
T	.08	.04	T	.05	.3		.08	.04	T	T	.05	T	.02
T	.01	.01	T	T	.1	T	.02	.5	T	T	.02	T	.1
T	.04	T	T	.02	.2	T	.04	T	.1	T	.03	.3	.09
	T			T	.02		T				T	T	T
	T	T	T				T	T	T	T			T
T	T					T	T	T					T
	T		T	T			T	T	T	T	T	T	T
	T	T			T	T	T	T	T		T		T
	T		T		T	T	T	.05	T	T	T	.01	.01
	T	T					T	T	T	T		T	T
	T	T					T	.05	T				.01
	.02	T			.05		.01	.03	T		T		.01

accords very closely with the record of six species in the bay for the year 1931-32, and four in 1917. *Calanus finmarchicus* never failed to exceed all other species in the monthly averages for all areas except in April in the bay when it was equalled by *Pseudocalanus*. However, in the western area in June it was but two per cent more numerous than *Metridia lucens*.

Two endemic boreal copepods, *Oithona similis* and *Microsetella norvegica*, because of their small size, could not be sampled in a representative manner with coarse metre nets. Both, however, were taken effectively in the fine nets and with the pump, and although these data are limited to the upper 50 metres, the two species are known to have their centre of abundance within that range in the present region in summer. The following table gives the mean abundance of adults in the total region between April and September in 1932, and for the two months August and September in 1931.

	April-June	August-September	
	1932	1932	1931
Oithona similis	2262	1941	1822
Microsetella norvegica	193	555	153

April-June results show the number per minute of towing; August-September, the number per cubic metre. Unfortunately, due to different methods used, it was not possible to determine the relative abundance of microcalanids and macrocalanids (adults). A comparison of some of the young in the total region is shown below, but cannot be considered even suggestive of the position of the adults in the quantitative scale of species, for as previously described (Fish 1936b), the degree of mortality in developmental stages apparently varies greatly in different forms.

	April-June	August-September	
	1932	1932	1931
Oithona similis	5,316	19,057	19,375
Microsetella norvegica	6	666	478
Calanus finmarchicus	3,729	509	2,022
Pseudocalanus minutus	13,304	4,573	12,735

Oithona, in which such a relatively minute percentage of the young reach maturity (Fish 1936c, p. 185), occupies at certain periods a dominant position in the scale of plankton larvae, but the adults have rarely been reported to form a significant part of the population except perhaps in restricted localities for short periods. The latter condition was also found in *Microsetella*, which in 1931 and 1932 was far less abundant than *Oithona*, but in 1930 swarmed during July and August in Frenchmans bay, outnumbering both adults and young of all other zooplankton species combined.

Rotifers were not represented in the coarser net collections, but the fine net and pump records showed them to be extremely abundant in certain localities, particularly during the late summer. In all four species were found: *Synchaeta johanseni*, *S. triophthalma*, *Trichocerca curvata*, and *Northolca foliacea*. For

identifications of these species we are indebted to Mr. Frank J. Myers, who examined specimens taken in Frenchmans bay by the senior author in 1930. As no previous list of marine rotifers in the gulf has been published we may add the following species recorded by Mr. Myers from Frenchmans bay, although the greater part is no doubt restricted to the immediate vicinity of the shore line.

Colurella ambleytela (Gosse). From algae clinging to the laboratory dock.
Encentrum eristes Harring and Myers. From *Fucus,* alongshore, Laboratory point.
Encentrum marinum (DuJardin). From *Fucus,* alongshore, Laboratory point.
Encentrum nesites Harring and Myers. From *Fucus,* alongshore, Laboratory point.
Lecane grandis (Murray). Tidepools near Sand point. Northern shore.
Notholca foliacea (Ehrenberg). Limnotic variation. Towings off Porcupine Is.
Proales neapolitana (Daday). From algae clinging to laboratory float.
Proales reinhardti (Ehrenberg). From algae clinging to laboratory float.
Proales similis (deBeauchamp). From *Fucus,* shore, Laboratory point.
Synchaeta baltica (Ehrenberg). Towings near Laboratory point.
Synchaeta johanseni Harring. Towings off Porcupine island.
Synchaeta triophthalma Lauterborn. Towings off Porcupine island.
Trichocerca curvata (Levander). Towings off Porcupine island.
Trichocerca marina (Daday). From *Fucus,* shore, Laboratory point.

Synchaeta johanseni was the dominant rotifer both in 1931 and 1932 in the open gulf and bay of Fundy, and in 1930 in Frenchmans bay. Regarding this species Mr. Myers wrote: "This is only the second time reported. Harring described this species from poor material sent him by F. Johansen from station 36, off Cape Lyon, in Amundsen Gulf, Alaska. Harring said that the form and position of the eyespot could not be made out from his material. Fortunately your material is fine and clears up all doubts about the eyespot; one large at posterior tip of ganglion and two accessory spots higher up in the head." In 1932 it was observed in the Quoddy region in April and by May was distributed in small numbers as far west as Penobscot bay. The seasonal maximum occurred in June west of Mount Desert, and in August in the central area and bay of Fundy, as shown in the following table.

TABLE VIII. Regional variation in abundance of *Synchaeta johanseni*. Net collections, April-June; pump collections, August-September

1932	Number per minute			Number per cubic metre	
Section	April	May	June	August	September
Casco bay	0	0	1549	377	..
Penobscot bay	0	368	2734	1,507	..
Mount Desert	0	795	0	320	..
Moose Peak	0	21	0	7,073	..
Passamaquoddy bay	29	110	560	15,052	0
Pt. Lepreau	0	214	0	12,491	0
Cape Spencer	0	300	T	4.146	10

There was at all times marked regional variation, with numbers reaching 31,687 per cubic metre in 1932 when propagation was centred in the northeastern part of the region around Grand Manan (fig. 24).

Trichocerca curvata ranked second in importance among the rotifers. In April (1932) none were found in the inner gulf or bay of Fundy but in the outer gulf small numbers appeared at one station in the western channel, two along the

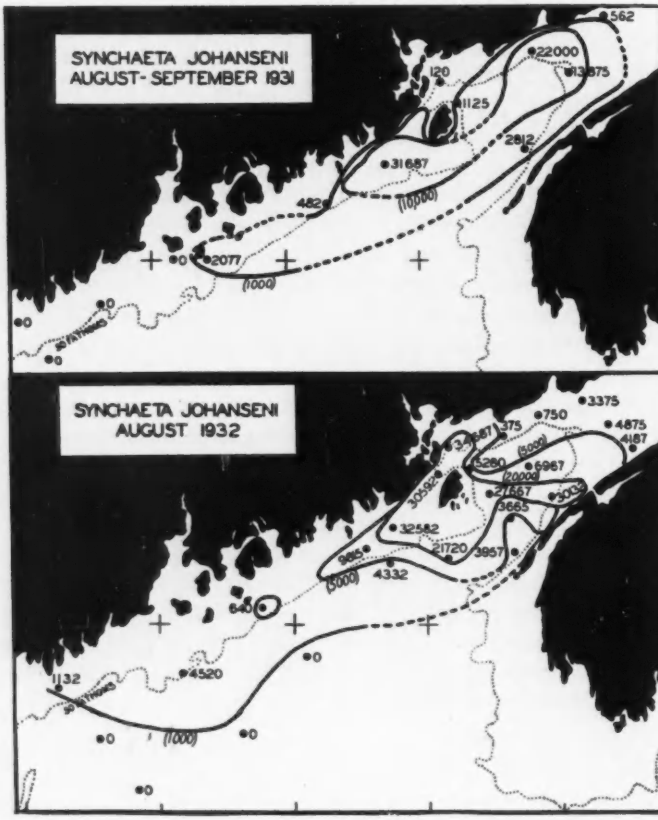


FIGURE 24 (part)

west coast of Nova Scotia, and four off the south coast. In May a few were taken at the outermost station off Penobscot bay (sta. 29) and on the Nova Scotian side of the bay (sta. 9A). In June it was found only in Passamaquoddy bay. The maximum occurred in August after which a rapid decline must have taken place, for none were obtained in September. In 1931 small numbers, up to 565 per cubic metre, were taken at three stations in the gulf and bay in August, but not at five stations in the bay the following month. Like *Synchaeta, Trichocerca* was cen-

tred in the vicinity of Grand Manan in August (fig. 24) and never appeared in appreciable numbers west of Mount Desert.

Synchaeta triophthalma occurred sparsely in the eastern part of the region in August and September of the two years. *Notholca foliacea* was not found in the gulf in 1931 or 1932, but in the bay a single specimen was taken at one station (11A) near shore in April and up to 565 per cubic metre at five stations in the

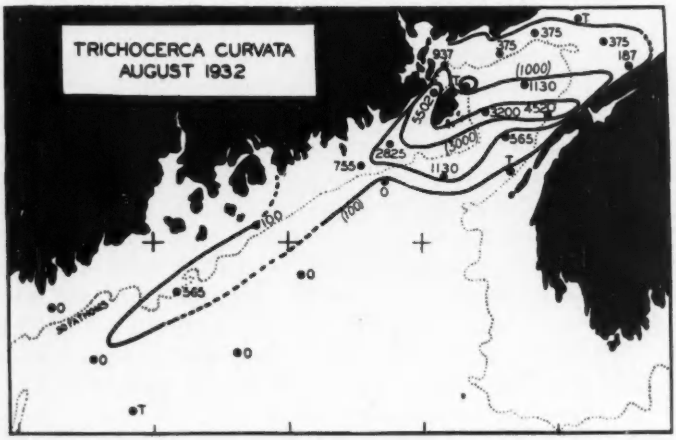


FIGURE 24 (con.). Distribution of dominant rotifers. Number per cubic metre.

inner bay in August. In 1930 a few individuals of both of these species were obtained in Frenchmans bay in August.

Although small in size rotifers may be important as food for plankton feeders in turbulent areas during the summer months. It is to these regions of violent mechanical mixing, particularly about Grand Manan, where minimum numbers of other planktonic species occur, that this group is largely restricted.

A similar condition was observed in Frenchmans bay in 1930. There *Synchaeta johanseni*, although swarming in the warmest season, was centred in the region of most violent mixing, the channel between Porcupine and Iron Bound islands. *Trichocerca curvata* was also found only in this locality in 1930.

It would appear that rotifers develop very rapidly and survive for so short a period that they do not become very widely dispersed, and like diatoms local concentrations may be considered indicative of production centres. All species reached a maximum in August.

OCEANIC IMMIGRANTS

Immigrant species, the means by which they reach the gulf of Maine, their seasonal variation and dispersal within the region, have been so fully described by Bigelow (1926, pp. 51-69) that little need be added except an evaluation of

their relative importance in the local population during the period of the present investigations.

Contributions from outside waters consist of six general classes: (1) endemic species transported as juveniles in the surface drift or entering later with the large volume of mixed water from the outer part of the continental shelf; (2) non-endemic or partially-endemic species like *Metridia longa* and *Calanus hyperboreus* whose centres of abundance lie in neighbouring regions to the north, and which depend largely, if not entirely, upon contributions from outside waters for the local stock; (3) non-endemic or partially-endemic species, as *Sagitta serratodentata* and *Paracalanus parvus,* from neighbouring regions to the southward; (4) arctic immigrants, like *Limacina helicina,* entering from the Nova Scotian current; (5) tropical migrants originating in the Gulf Stream (*Salpa* and *Phronima*), and (6) deep water forms entering with the cold bottom influx through the eastern channel (*Sagitta maxima* and *Diphyes arctica*).

The greater part of all zooplankton forms entering the gulf throughout the year are endemic boreal species, but an evaluation of their importance cannot be made with available data as they are indistinguishable from the local stock and their abundance and distribution beyond the confines of the gulf have not been sufficiently well determined. Differences in the periods of propagation, if indeed they occur, would make possible a detection of young stages passing into the gulf, but there seems little possibility of calculating effectively the augmentation by adults.

The remaining classes, for present purposes, have been combined in two groups and designated as northern or southern, depending on whether they originate in colder or warmer water than that characterizing the region of the gulf and bay of Fundy.

Northern group. The following seven northern forms were taken within the gulf during the two years: *Metridia longa* and *Calanus hyperboreus* (northern); *Limacina helicina, Aetidius armatus* and *Scolecithricella minor* (arctic); *Sagitta maxima* and *Diphyes arctica* (deep water). *Hyperoche tauriformis* has frequently been taken in the region, and averaged 2.4 per cent of the population at four stations off the south coast of Nova Scotia on January 21, 1932, but did not appear in any of our collections from the gulf or bay of Fundy. To these may be added the following species, classed as northern, which were absent in present collections but have previously been reported from the gulf (Bigelow 1926, p. 598): *Ptychogena lactea, Mertensia ovum, Oikopleura vanhöffeni, Scaphocalanus magnus, Chiridius armatus, Chiridius obtusifrons, Gaidius brevispinus, Gaidius tenuispinus, Heterorhabdus norvegicus,* and *Scolecithricella ovata.*

Another species, *Clione limacina,* assigned to the northern group by Bigelow (1926, p. 61), has been included with local boreal species in the present arrangement because, although its centre of abundance lies in more northern waters, it more closely approaches the endemic stock than the members of the northern group. The numbers of young in all stages of development in the gulf and bay both in 1931 and 1932 were more than sufficient to account for the local adult

stock, and would indicate that the species is endemic at least as far south as cape Cod, and probably farther. Dr. Mary Sears has informed us that she has found early and late developmental stages in large numbers over a wide area south of the cape, and in 1922 and 1923 we obtained occasional early larvae at Woods Hole. Dr. Huntsman (Bigelow 1922, p. 134) also reported larvae widespread throughout the region from the gulf of Maine to the gulf of St. Lawrence, but not in estuaries. However, a significant part of the stock of *Clione* and also of *Tomopteris catharina* is probably derived from more prolific areas north of the gulf. The latter species occurred throughout the year 1931-32 in the bay of Fundy, appearing in all stages of development, but Bigelow has found evidence that it fails to reproduce successfully in the gulf in certain years (1926, p. 68). Large local swarms of either species would be considered indicative of immigration.

Evaluation of species. Northern species in the bay of Fundy averaged for the year October 1931 to September 1932 as follows: *Metridia longa* 0.2 per cent, *Calanus hyperboreus* 0.03 per cent, *Sagitta maxima* T, *Limacina helicina* T, *Diphyes arctica* T, and *Aetidius armatus* T. *Scolecithricella minor* appeared in September, 1931, but was not found in 1932. In 1917 no typically arctic species were observed but northern species were relatively more important than in 1931-32. In the former year *M. longa* attained a maximum of 2.9 per cent in the bay in February, and averaged 0.9 per cent for the year. *C. hyperboreus* averaged 13.4 per cent in June, 2.5 per cent in July and 1.8 per cent for the year. *M. longa* occurred in the bay in every month both in 1917 and in 1931-32. *C. hyperboreus* was lacking in collections in April, 1917, and from December to March in the latter year. It might be suggested from these data that the small stock of *C. hyperboreus* in the bay tends to become depleted in the late winter and early spring and is in some instances exhausted before vernal restocking from outside waters takes place. Observations by Willey (1921, p. 191) indicate that late copepodite stages surviving the winter in the bay complete their metamorphosis, although he did not report any females with eggs, and no nauplii were found in the course of the present investigations.

The following mean values for the total region during the period from April to September, 1932, are very similar to those for the year in the bay: *M. longa* 0.1 per cent, *C. hyperboreus* 0.04 per cent, *S. maxima* T, *L. helicina* T, *D. arctica* T, and *A. armatus* T. Considered by areas, the central area corresponded very closely with the bay, but west of Mount Desert *M. longa* was not taken after April, and *C. hyperboreus* occurred at but one station after June. This agrees with Bigelow's finding that "Evidently the numbers of *C. hyperboreus* existing in the gulf increase considerably from February to May and then decrease during June, while none at all have been detected at most of the midsummer and autumn stations." (1926, p. 215.)

Sagitta maxima enters the gulf throughout the year in the cold bottom water (Bigelow 1926, p. 327) and in 1932 was found widespread in the region at seven stations in April, five in May, eleven in June, twelve in August, and four in Sep-

tember. In the bay of Fundy it also occurred in September, October, and December 1931, and in January and March 1932.

Typically arctic forms were found by Bigelow (1926, pp. 60-61) in greatest abundance and most widespread in May, being closely associated with the seasonal

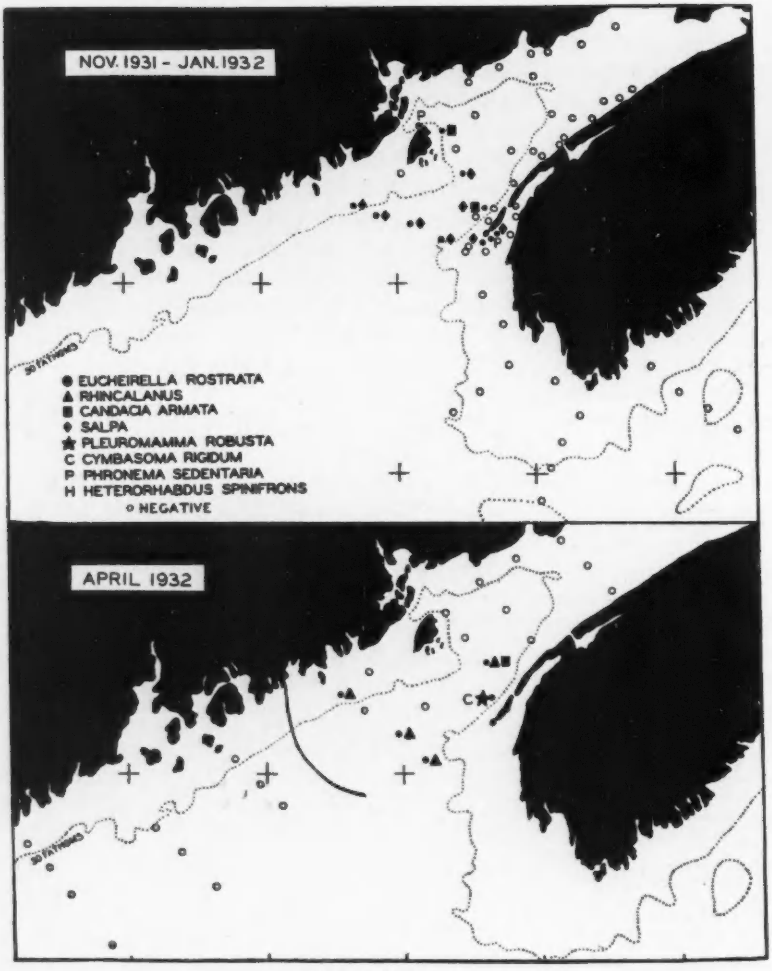


FIGURE 25 (part)

expansion of the Nova Scotian current. Variations take place from year to year, however, and in 1932 the first arctic species, *Aetidius armatus*, appeared at the outermost station (sta. 29) in one of the western sections on May 30. Another specimen of this species was obtained in the bay of Fundy (sta. 10A) in August.

Limacina helicina (sta. 10A) and *Diphyes arctica* (sta. 11A) were found at adjoining stations in the inner bay on June 21, the latter also occurring at sta. 33 in the central area and later at five widely separated stations throughout the region in August. In 1931 *Scolecithricella minor* was taken in the bay in September.

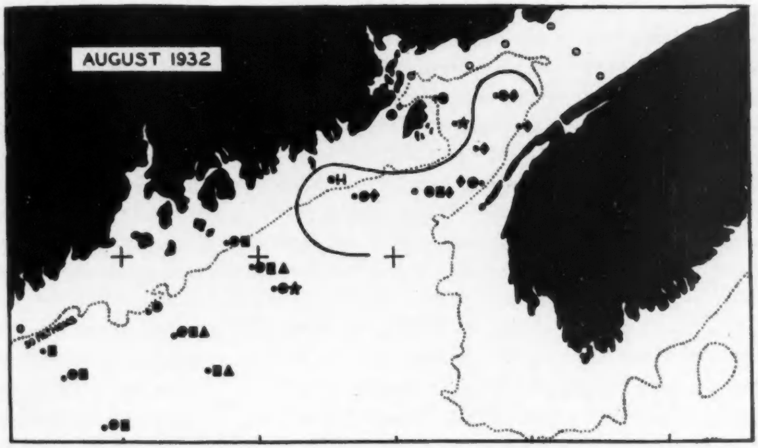


FIGURE 25 (con.). Distribution of tropical species.

Except as indicators, arctic immigrants are of little value in the region and usually appear as single individuals in the hauls. The northern forms *M. longa* and *C. hyperboreus* and the deep water species *S. maxima* regularly occur in somewhat greater abundance but they, too, are rarely present in significant quantities over the region as a whole. *M. longa* reached 4.8 per cent on one occasion (sta. 12 in April) and *C. hyperboreus* at sta. 7 in May amounted to 1.6 per cent, but the average for the region in each instance in 1932 did not exceed 0.3 per cent. *S. maxima* also formed 4 per cent of a haul in the deep basin at the entrance of the bay in January 1932, but occurred at only two other stations out of 43 in the region that month. All of these concentrations were observed in the bay where the numbers of immigrants tend to loom proportionately larger than elsewhere in the region because of the small local zooplankton population.

Southern group. Unlike the northern group, of which almost all of the pelagic species found in the arctic drift have on occasions been taken well inside of the gulf, a relatively small fraction of the Gulf Stream population penetrates far shoreward of the outer banks. Almost any of the myriad of tropical surface species may be expected along the south side of Georges bank, but year after year only the same comparatively few species appear to survive sufficiently long in boreal waters to become very widely distributed. Even so the number of species far exceeds those from the north.

In 1931-32 the following ten species were found in the inner coastal area:

Candacia armata, Cymbasoma rigidum, Eucheirella rostrata, Heterorhabdus spinifrons, Pleuromamma robusta, Phronima sedentaria, Rhincalanus nasutus, Salpa fusiformis, Salpa zonaria, and *Sagitta serratodentata*. In September 1932, six additional southern species were obtained offshore in the vicinity of Georges bank: *Corycaeus elongatus* (sta. A1415), *Nematoscelis megalops* (A1400, A1412, A1413), *Sagitta inflata* (A1415, A1416), *Ocypoda albicans* megalops (A1413, A1414), *Odontodactylus sp.* larvae (A1414), and *Thysanoessa gregaria* (A1414).

It seems probable that *Paracalanus parvus* should be included with the southern group in the western Atlantic because its centre of abundance is certainly located south of cape Cod (Wilson 1932a, p. 39, 1932b, p. 26), and, although it appears to propagate successfully and become fairly numerous in the gulf in some years (Bigelow 1926, p. 267), it is almost if not entirely absent in others. Young stages were found in September 1931 and from April to September in 1932, indicating the presence of a very small adult stock, but they were so sparse that not one individual appeared in the metre net collections of the two years or in those from the bay of Fundy in 1917.

Tropical communities enter the gulf sporadically during the summer, usually between April and September, and successive waves may be composed of quite different associations depending on the nature of the stock in the Gulf Stream at the time. Thus in April 1932 (fig. 25) four tropical species, *Rhincalanus nasutus, Pleuromamma robusta, Candacia armata*, and *Cymbasoma rigidum*, were found restricted to the eastern gulf and the drift into the bay of Fundy. By mid-May *Eucheirella rostrata* appeared and ranged from the eastern channel around the margin of the gulf to Penobscot bay and well into the bay of Fundy. By this time *Rhincalanus* had advanced at least as far west as Casco bay. A second wave of immigrants (fig. 25), dominated by *Salpa fusiformis*, appeared in August with a distribution corresponding closely with that of the former group in April. Of the earlier migrants only *Eucheirella* and *Pleuromamma* remained in the bay and *Rhincalanus* in the central coastal area (Mount Desert and Penobscot bay sections). In September observations, including the outer gulf, indicated conditions over much of the region similar to the inner gulf in August, except that *Phronima* occurred at one station in the central area, all stations along the inner edge of Georges bank, and one on the bank. A second influx of *Rhincalanus* was found in the drift entering the bay of Fundy on September 15-16. A September invasion of *Pelagia noctiluca*, observed for the first time in Canadian waters, was reported in 1934 (Leim and Hachey 1935, p. 280).

In the case of the genus *Salpa*, one of the most typical of the tropical migrants, it is not known whether the stock in the Gulf Stream is so completely dominated by one species at a time as would be inferred from the distribution of immigrants in boreal waters. So far there is no record of two species occurring in the gulf at the same time, even though successive invasions during a season may be composed of different species. Of five species taken by Bigelow in the Gulf Stream south of cape Cod in 1913, only one, *S. tilesii*, was reported from the gulf. In 1931, *S. zonaria* appeared in mid-September along the Nova Scotian side of the

bay, and a few weeks later entered the Quoddy region. In the vicinity of St. Mary bay (fig. 25) it remained throughout the autumn and formed 24 per cent of the population at one station (N40) in January 1932. *S. fusiformis* appeared in August (1932) in the eastern gulf, and was later found on the southern part of Georges bank in September (sta. A1415). Again in June 1934 collections from the region of Georges bank yielded a large number of *S. zonaria,* while a half metre oblique net haul in the same region in August yielded over three quarts (2.8 litres) of *S. democratica-mucronota* in 15 minutes. Other similar occurrences in the gulf have been described by Bigelow (1914a, p. 121; 1917, p. 245; 1926, pp. 56-57), in each instance the *Salpa* stock being composed of one species. Subjected to uniform mechanical action and evidently able to survive equally well in boreal waters during the warm season, one would expect the species of *Salpa* entering the gulf to be in much the same relative proportion as in adjacent ocean waters. Pending acquisition of the necessary data, it would appear logical to conclude that wide seasonal fluctuations in abundance do occur within the Gulf Stream, as suggested by Bigelow (1909, p. 199), and that immigrants in the gulf are indicative of the particular species dominating at the time.

Evaluation of species. In the bay of Fundy average values of southern forms for the year 1931-1932 were negligible. *Sagitta serratodentata*, the most important species with a yearly mean of 0.04 per cent, amounted to only 0.2 per cent of a scanty population when it occurred in greatest abundance in March. It was found, however, in every month except October, January, and possibly February (collections destroyed by fire). In 1917 it appeared in but one haul, in November. Seven tropical species occurred as traces in the bay in 1931-32; *Candacia armata* (June, September, November, December), *Cymbasoma rigidum* (June), *Eucheirella rostrata* (May, June, August, September), *Pleuromamma robusta* (August, September), *Rhincalanus nasutus* (June, August, September), *Salpa fusiformis* (August 1932), and *Salpa zonaria* (September, November, December in 1931, and January 1932).

Values for the total region between April and September 1932 were of the same general order. *S. serratodentata* averaged 0.03 per cent in the western area, 0.04 per cent in the central area, and 0.02 per cent for the entire gulf and bay. All other species occurred as traces. The central area yielded the largest number of species (eight) and the western area the smallest (four).

NERITIC SPECIES (IN OFFSHORE WATERS)

The term neritic should rightly apply to all forms associated with the coast or shallow waters, and neritic plankton would include true planktonic species, pelagic fish eggs and larvae, and the pelagic eggs and larvae of benthonic coastal species. In the present analyses, these three classes have been evaluated separately and the term "neritic species" restricted to those coastal forms which are pelagic as adults. In the region of the gulf of Maine this group is composed of copepods, Cladocera, and Medusae.

In all, 26 neritic species were obtained during the period of the present investigations. Of these seven were copepods, three Cladocera and sixteen Medusae.

With the exception of two species, *Acartia bifilosa* and *Thalestris longimana,* which were found only within bays in the western and central areas, all of the species were at some time taken within the range of the routine offshore stations. Four species, *Podon polyphemoides, Podocoryne carnea, Steenstrupia virgulata,* and *Tiaropsis diademata* reported in 1931 did not appear in the collections of the second year.

It is probable that few additions will be made to the list of neritic Crustacea (excluding benthonic species) found in offshore waters of the gulf, but our records of Hydromedusae are far from complete. Occurring frequently for very short periods at the surface, they are easily missed on monthly cruises.

All boreal neritic species appear to be seasonal in the plankton and pass a portion of the year at the bottom. Some, like the Hydromedusae, remain as active organisms in the benthonic state while others (Entomostraca) have a resting stage, usually in the form of winter eggs. In this respect they resemble fresh water populations (excluding marine relics) and quickly disappear when unfavourable environmental conditions are encountered. The boundaries of their normal geographical range are thus much more clearly marked than those of the offshore population. An alongshore drift further assists in retaining neritic forms in the immediate vicinity of the coast over much of the gulf, but the increasing percentage of this group encountered upon approaching the outer headlands from offshore indicates that considerable quantities are constantly drawn seaward in the general circulatory drift. Particularly in the productive sector from Penobscot bay to Casco bay, adequate means of transportation almost directly offshore are provided as soon as the narrow band of alongshore drift has been traversed (through tidal action), and, were it not for other limiting factors, neritic species would become widely distributed over the basin in a very short time. However, like stream species restricted to the immediate vicinity of outwash into lakes (Fish 1929, fig. 77), Bigelow (1926, pp. 32 and 36) rarely found the neritic population of the gulf more than a few miles offshore.

The regional distribution in 1931 and 1932 accords very well with previous observations. In the gulf of Maine, for the period April to September in 1932, neritic zooplankton formed but 0.5 per cent of the population in the western area, and 0.7 per cent in the central area (table IV). Data from other parts of the gulf in May indicated neritic species forming 0.6 per cent off cape Ann, 0.2 per cent in the central part of the western basin, and absent in the central basin, eastern channel and Browns bank. Again in September traces were found in the western area and outer gulf (off the inner margin of Georges bank), but not in the central area, Georges bank, or the west coast of Nova Scotia (table VI).

The change in the composition of the population upon approaching the coast is illustrated in the records of August during the two years. In 1931 stations were taken on a line roughly paralleling the coast and, with two exceptions, within the 100 metre contour (fig. 1), seven of the eleven stations in the gulf being well

inside of the area covered during the following year. Neritic species in the two regions of the inner gulf yielded the following mean values:

August	*Western area* (per cent)	*Central area* (per cent)
1931	27.0	15.6
1932	1.3	3.1

Even at the innermost stations (excluding bays) members of the open gulf population did not fall below 63 per cent during the two years.

In the bay of Fundy the zooplankton was found to be somewhat more neritic in character than in the gulf, although the mean for the year October 1931 to September 1932 amounted to only 1.9 per cent. A slight summer increase over the western area was noticeable east of Mount Desert and the percentage rose still higher in the bay (table IV). The larger values in the eastern region were, however, due more to the small stock of offshore boreal forms than to an actual increase in the number of neritic species, as is indicated by the volumes in the different areas at this time (figs. 16 and 17). The mean in the bay for the period July-September in 1931 was 5.6 per cent and in 1932, 5.9 per cent. The same three forms, *Acartia, Evadne,* and *Phialidium* dominated the neritic stock throughout the entire region at this time. At other times during the year the monthly average in the bay did not exceed 0.7 per cent (table V).

Available records indicate that north of cape Cod the neritic community is for the most part a summer one, having its origin in April and termination in October. The greater part of the neritic species in 1931-32 did not appear before May or after September in the bay of Fundy. But one exception was observed during this period: *Acartia longiremis* occurred sporadically in small numbers throughout the year. In 1917, however, it was taken only in April. During the colder months open gulf species populate the entire region including inshore waters. With vernal warming neritic species become numerous first in the more shallow bays, and, except in deeper areas where low bottom temperatures persist, may largely replace the winter stock in inland waters. There follows a progression of seasonal changes in the neritic population as new forms appear and others decline until autumn. At this time in 1931 the summer stock, at least in the bay of Fundy, disappeared and was replaced by an invasion of the offshore population. (For a more detailed account of seasonal changes in the neritic community see p. 300.)

The annual cycle of the neritic community in boreal waters in 1931-1932 contrasts in an interesting manner with that of the region immediately south of cape Cod. In the vicinity of Woods Hole neritic species occur throughout the year, being divided roughly into two groups—a summer community and a winter community (Fish 1925, p. 141). In early summer *Acartia tonsa* usually dominates. Later *Pseudodiaptomus coronatus* appears, reaches its peak in late fall and remains well into the cold months. The winter community is composed of a much larger number of neritic species, *Acartia clausi, A. longiremis, A. bifilosa, Eurytemora herdmani, E. hirundoides,* and *Centropages hamatus. Tortanus discaudatus*

appears during the late winter, reaches its maximum in February and March, and declines with the warming of the water. Considering this seasonal variation it will be seen that the summer and autumn forms are southern ranging species (Wilson 1932b) not reported from the gulf of Maine, and the winter and spring forms are boreal species which in 1931 and 1932 comprised the summer neritic community in the gulf.

Reflecting to a large extent conditions in inland waters, considerable annual variation may be expected in the neritic stock occurring in the open gulf and bay. The extent of this variation cannot be clearly determined on the basis of available records. Certainly there is no distinctly winter neritic community corresponding to that occurring south of the cape, although a wide range in the seasonal occurrence of some of the neritic species which formed the summer population in 1931-1932 has been reported by previous observers. In the case of *Acartia clausi*, one

TABLE IX. Neritic zooplankton species. Relative

Area	Total region					Western area		
Month 1932	Apr.	May	June	Aug.	Sept.	Apr.	May	June
Cruise	26	27	28	30	32	26	27	28
Acartia clausi				.01				
Acartia longiremis			.1	.2	.8			T
Centropages hamatus				T				
Eurytemora herdmani				T	T			
Tortanus discaudatus	.01	.01	T	T	.01		T	T
Evadne nordmanni	T	.06	.1	2.1	T	T	.2	.4
Podon leuckarti			.1	T				.6
Bougainvillia superciliaris		T	T	T				
Halopsis ocellata		T	.05	T			T	T
Hybocodon prolifera	.01	.1	.02			T		
Melicertum campanula				T				
Mitrocoma cruciata		T	.03				T	T
Obelia sp.		T	T	T	T			T
Phialidium languidum	T		T	4.4	1.1			T
Sarsia sp.		T	T	T	T			
Staurophora mertensii		T	T	T				T
Syncoryne mirabilis		T						
Turris vesicaria				T	T			
Aurelia aurita	.07	T	T					
Cyanea capillata var. arctica		T	T	T				T

of the most important neritic species, its presence in the gulf in the summer of 1912 and 1915, and apparent absence during the winter of 1912-13 would accord with more recent observations. On other occasions it has been taken in the spring (1915, 1920) and winter (1920-31) (Bigelow 1926, pp. 172-174). Willey (1921, p. 187) also found it forming 68 per cent of the copepod population of Passamaquoddy bay on January 16, 1920. On the basis of these records Bigelow suggested two breeding seasons for *A. clausi* in the gulf, one in early spring and the other in late summer. It may be suggested that the late summer season may prove to be more general and represent the local stock, and that in some years winter breeding, centred south of cape Cod, may extend east into the gulf to form an early spring crop. This is indicated by the absence of spring records from the bay of Fundy and the fact that the largest numbers in April 1915 were recorded

in the outer banks (Georges and Browns) and off cape Cod (Bigelow 1926, p. 175). Considerable seasonal variation is also indicated in previous records for other species of neritic copepods, but with the exception of *A. clausi* all show a definite maximum in summer and early autumn and a minimum in winter and early spring. Earlier records of Cladocera are all limited to the period between June and September (Bigelow 1926, p. 307) and Medusae between April and October.

Evaluation of species. The quantitative variation of neritic species was even more marked than their restricted geographical range. The local irregularities commonly encountered offshore would quite naturally be expected in regions where the neritic populations of neighbouring bays are frequently dominated by different species (p. 288). Qualitatively each bay must be considered as an independent unit, but for the inner gulf and bay of Fundy outside of the headlands,

percentages in metre net collections in 1932.

		Central area					Bay of Fundy				
Aug.	Sept.	Apr.	May	June	Aug.	Sept.	Apr.	May	June	Aug.	Sept.
30	32	26	27	28	30	32	26	27	28	30	32
										.05	
T				.1	.2				.3	.5	2.5
										.01	
										.01	T
T		.04						.03	T	.01	.04
.6			.03		2.3			.01	.03	2.7	T
				T						T	
T								T	T	T	
T			T	.04				T	.1	T	
							.04	.4	.06		
T					T					T	
			T	T				T	.1		
T			T	T				T		T	T
.7	T	T			.6				T	8.4	3.4
T	T		T	.02	T			.02			
				T				T	T	T	
			T								
T					T					T	T
							.2	T	T		
			T					T	T	T	

values obtained by averaging all stations in each of the general areas are considered reasonably representative, at least for the more abundant species.

Of the two common species of Scyphomedusae, swarms of *Aurelia aurita* were frequently encountered in bays, but with one exception, at station 10 in the bay of Fundy, on September 4, 1931, never offshore in quantities sufficient to interfere with the normal fishing of the nets. Whenever taken this species was observed at or near the surface during the interval of towing, and the numbers in the hauls would indicate that it was concentrated largely in the upper levels and captured in representative numbers. *Cyanea capillata var. arctica* appeared in oblique hauls but was less frequently seen at the surface. Again the frequency with which the long tentacles were found on the cable and net bridle when none appeared in haul suggests that this species is widespread near the coast in deeper

water. When one considers the length of the expanded tentacles of *Cyanea*, it is not surprising that less than 10 per cent of those coming in contact with the lines entered the nets, and there is no reason to suppose that the collection records are any less representative than in the case of *Aurelia*.

Bay of Fundy. As previously stated, but one neritic form, *Acartia longiremis*, was taken between October 1931 and April 1932, and this reached its peak in September. Its occurrence during the year was as follows: 1931, July 0.1 per cent, August 0.05 per cent, September 0.02 per cent, November T, December 0.04 per cent; 1932, January 0.7 per cent, March 0.3 per cent, June 0.3 per cent, August 0.5 per cent, September 2.5 per cent. The values for other species during the period, April to September, are shown in table IX. Until mid-summer the total of all neritic species did not exceed 0.6 per cent at any time. *Phialidium* then increased to 8.4 per cent of the population, and *Evadne*, 2.7 per cent in August. The former species remained abundant (3.4 per cent) and with *Acartia longiremis* (2.5 per cent) dominated the neritic stock in the bay in September.

Comparing the mean values for the period, July-August in 1931 (shown below) and 1932 (table IX), the most striking difference occurred in *Acartia clausi*, which appeared much later in the second year (p. 294), and, although abundant in Passamaquoddy bay in late summer, had not become very widely distributed in the bay of Fundy by September.

	Per cent		Per cent
Acartia clausi	4.0	*Obelia sp.*	0.07
Acartia longiremis	0.06	*Phialidium languidum*	1.3
Tortanus discaudatus	0.07	*Podocoryne carnea*	T
Evadne nordmanni	0.07	*Tiaropsis diademata*	T
Podon leuckarti	T	*Turris vesicaria*	T
Podon polyphemoides	T	*Aurelia aurita*	T

Phialidium in both years formed an important member of the neritic population of the bay, a population totalling 19 species. Of these, 16 species were found in 1932 and 12 in 1931. Seven of the species taken in 1932 did not appear in the collections from the bay in the first year, and two species occurred only in 1931.

Inner gulf. In the inner gulf during the summer of 1932, 15 neritic species were taken in the western area and 13 in the central area (table IX). Of these, three, *Bougainvillia, Hybocodon*, and *Obelia*, found in the western area, did not appear in the central area, and one, *Syncoryne*, occurred only in the latter. Because of the small numbers involved these distribution records are not significant, and it is probable that all species range throughout the region, as indicated by the fact that all reported from the western area in 1932 were also found in the bay of Fundy.

The values in the gulf were at all times almost negligible, never exceeding 1.3 per cent in the western area even at the peak of the season (August). In the central area the actual numbers were still less, but due to a smaller representation of offshore species, the percentages of neritic forms were at times somewhat higher, reaching 3.1 per cent in August when *Evadne nordmanni* dominated.

Outer gulf. Both in the eastern and western Atlantic neritic species have been reported on offshore banks, the populations frequently corresponding to some extent with those at similar depths in the neighbouring coastal zones. On the Grand banks in early June 1924 the senior author found the following neritic species together with larvae of numerous benthonic species: *Centropages hamatus, Cyanea capillata, Lizzia grata, Sarsia flammea, S. mirabilis, Tiaropsis diademata,* and *Turris vesicaria.*

In the gulf of Maine Bigelow (1926) reported *Acartia clausi* at times numerous in the vicinity of the outer banks (p. 174), *A. longiremis* particularly in the region of Georges and Brown banks (p. 177), and *Tortanus discaudatus* on German bank (p. 294). In 1927 *Acartia clausi* and *Centropages hamatus* were taken on Georges bank in early August. Medusae have also been reported frequently from this region by Bigelow.

There are unfortunately no data from the offshore banks at the peak of the season (August) in 1931-32, but observations in April and September of the second year indicate that the numbers of neritic forms were everywhere very sparse in the outer gulf. In May stations in the eastern channel, Browns bank, and the central basin of the gulf yielded no neritic species, but in the western basin one species, *Evadne nordmanni* averaged 0.2 per cent. In September negative results were obtained on Georges bank, off the west coast of Nova Scotia, and the central area of the gulf, but a few specimens of *Turris vesicaria* were found along the inner margin of Georges bank. It would thus appear that neritic species may be expected in the region of offshore banks, particularly during the propagation seasons, but they are evidently more irregular and remain for shorter periods than in the coastal zone. They are rarely very widespread offshore at any time.

As the area covered in the gulf in 1931 extended well inside of the 100 metre contour (fig. 1), the results are not comparable quantitatively with those of 1932. They are, however, indicative of a marked increase of neritic forms upon approaching the coast, as mentioned on p. 253, although the number of different species was less in both the western and central areas than in 1932. Had observations extended throughout the summer in 1931 the number of Medusae at least would certainly have been greater.

Two species, *Podon polyphemoides* and *Podocoryne carnea,* widespread in both the gulf and bay in 1931, were not found the following year, even in bays visited in August and September. A third species, *Steenstrupia virgulata,* found only in the western area during the first season, was also not taken again. Comparing table IX with the following records for August 1931 in the gulf, it will be seen that seven species were added in 1932:

	Western area (per cent)	*Central area* (per cent)
Acartia clausi	2.0	3.3
Acartia longiremis	1.9	5.0
Centropages hamatus		.02
Eurytemora herdmani	.8	.02

	Western area (per cent)	Central area (per cent)
Tortanus discaudatus	2.1	.14
Evadne nordmanni	6.8	3.1
Podon leuckarti	4.2	T
Podon polyphemoides	7.2	3.3
Melicertum campanula		T
Obelia sp.	.6	.1
Phialidium languidum	1.3	.6
Podocoryne carnea	T	T
Steenstrupia virgulata	.07	

FISH EGGS AND LARVAE

Almost all teleosts in the gulf of Maine have pelagic young, and in a relatively large percentage the eggs are buoyant. With few exceptions, they are endemic boreal species. Exceptional are the larvae of *Zoarces anguillaris* (viviparous) and *Opsanus tau* (demersal eggs) which apparently remain at or so near the bottom that they are not taken in plankton collections.

Number of species. Within the gulf, Bigelow and Welsh's records (1925) indicate that approximately 54 species probably breed to some extent, and the larvae of at least 41 may be expected in the open waters north of cape Ann. Neritic minnows and summer migrants, with the exception of *Scomber scombrus* and possibly *Poronotus triacanthus,* would be excluded. Prior to 1931 pelagic eggs of about 15 and larvae of some 31 species had been identified in tow net collections from the gulf and bay of Fundy. Immigrant elvers of *Anguilla rostrata* had also been regularly taken between February and April (Bigelow and Welsh 1925).

The present collections, not covering the winter months in the gulf, have yielded young of 28 species and distinguishable eggs of 10 species. Probably some *Melanogrammus* eggs were taken in April and May, and *Merluccius* during the summer, but as none were in advanced stages, the former were indistinguishable from those of *Gadus* and the latter from *Enchelyopus. Merluccius* eggs in late embryonic stages, and larvae were found in some of the bays, particularly in the western area in August, 1929 and 1932 (see table XIX).

The larvae and fry represented 24 detectable endemic species, one questionable form, *Siphostoma fuscum* (possibly endemic) from Georges bank, and three not identified. Eggs and young taken during the period from July 1931 to September 1932 are listed below.

Ammodytes americanus (larva)
Anarhichas lupus (larva)
Anguilla rostrata (elver)
Argentina silus (fry)
Aspidophoroides monopterygius (fry)
Brosmius brosme (egg and larva)
Clupea harengus (larva and fry)

Cyclopterus lumpus (fry)
Enchelyopus cimbrius (egg and larva)
Gadus callarias (egg, larva and fry)
Glyptocephalus cynoglossus (egg and larva)
Hippoglossoides platessoides (egg and larva)
Leptocephalus conger (larva)
Limanda ferruginea (egg)
Lophopsetta maculata (larva)
Lumpenus lampetraeformis (larva)
Melanogrammus aeglifinis (larva and fry)
Merluccius bilinearis (larva)
Myoxocephalus scorpius (larva)
Neoliparis altanticus (larva)
Pholis gunnellus (larva)
Pollachius virens (larva)
Sebastes marinus (larva)
Siphostoma fuscum (fry)
Tautogolabrus adspersus (egg and larva)
Urophycis chuss (egg)
Scomber scombrus (egg)

Comparing the gulf with adjoining regions, immediately south of cape Cod, Edwards obtained 34 species of larval fishes at Woods Hole over a period of fifteen years, and the senior author 21 species in 1922-1923 (Fish 1925). There, however, the composition of the population is different, and at least 50 per cent of the larvae taken were migratory southern ranging species which enter the region and breed during the summer. East of the gulf, Dannevig (1919, p. 5) lists 36 species of eggs and larvae obtained in Canadian waters between May and August in 1915, of which only about 15 were taken off the eastern Nova Scotian coast. The latter area he found populated by definitely boreal species as contrasted with boreo-arctic forms encountered upon approaching Newfoundland.

Seasonal variation. Unlike the pelagic invertebrate population of the gulf in which there was no evidence of appreciable breeding between October and March, with the exception of *Pleurobrachia pileus* (p. 300), fish eggs and larvae were found throughout the year. Of the 54 species mentioned on p. 258, 31 spawn between May and September, 9 between February and April, and 14 in late autumn and winter.

Winter spawners include most of the sculpins, some of the blennies (*Pholis, Lumpenus*), gadoids (*Pollachius, Microgadus, Urophycis tenuis*), flounders (*Paralichthys dentatus, Pseudopleuronectes dignabilis*), and a few others like *Liparis, Cryptocanthodes* and *Anarhichas*.

The number of summer breeders is enlarged by small forms frequenting inland waters such as *Fundulus, Menidia, Pungitius, Gasterosteus,* and *Apeltes,* and southern ranging species restricted largely to Massachusetts bay during the warm months, *Cynoscion, Tautoga,* and *Paralichthys oblonga* (*Roccus, Steno-*

tomus, and *Spheroides*, brackish water spawners, enter the region, but probably never breed there). Omitting these two groups there remain approximately 18 known endemic species whose early larvae can be expected offshore in the gulf during the summer, a number not very much larger than the winter group.

The spring group appearing during the period of greatest zooplankton augmentation, comprises some of the most numerous fishes in the region, *Clupea*, *Gadus*, *Melanogrammus*, *Pseudopleuronectes americanus*, *Ammodytes*, *Cyclopterus*, and *Myoxocephalus aeneus*. At least one spring spawner, *Gadus*, continues breeding well into the summer in the eastern gulf.

The breeding season of at least one species, *Zoarces anguillaris*, may be restricted to late autumn. Another, *Clupea harengus*, spawns in both spring and autumn in some localities in the eastern portion of the region, but only during a

TABLE X. Total numbers of young fishes taken during the

Locality	Western area				
Number of stations	7	7	7	7	2
1932	Apr.	May	June	Aug.	Sept.
Ammodytes americanus	3	1			
Anguilla rostrata (elver)	1				
Argentina silus					
Asidophoroides monopterygius					
Brosmius brosme				9	
Clupea harengus					
Enchelyopus cimbrius			2		
Gadus callarias (larva)					
Gadus callarias (fry)			4		
Glyptocephalus cynoglossus				7	
Hippoglossoides platessoides			12	1	
Leptocephalus conger (leptocephalus)					
Lumpenus lampetraeformis				3	
Melanogrammus aeglifinus			7		
Merluccius bilinearis					
Myoxocephalus octodecimspinosus					
Myoxocephalus scorpius					
Neoliparis atlanticus					
Pholis gunnellus					
Pollachius virens (fry)					
Sebastes marinus			1331	1565	

relatively short period in late summer or autumn in the western gulf, the season tending to be progressively later to the westward (Bigelow and Welsh 1925, p. 25). South of cape Cod, at Woods Hole, no larval *Clupea* were taken in 1922 or 1923, but Edwards found them in varying abundance each year from 1893 to 1907 (Fish 1925, fig. 76). Although appearing in every month except August at sometime during this period, in 10 of the 15 years there were very definite spring and autumn groups, occurring most commonly in April-May and November-December.

1931 and 1932. Eggs taken during the winter months in the bay of Fundy proved particularly troublesome because they were almost invariably in early stages and could not be identified with certainty. It would appear that in 1931-32 cod (1.4-1.45 mm.) may have continued spawning through October, and pollock (1.15-1.2 mm.) from November to January (February records destroyed) in New

Brunswick waters. On the Nova Scotian side of the bay what are assumed to have been cod (1.42-1.7 mm.) had begun to spawn as early as January 6. No cod or pollock larvae were taken during this time and with the exception of two specimens of *Clupea harengus,* one (24 mm.) at sta. 5 on November 11, and another (21 mm.) at sta. 6 on November 12, no larvae appeared after September 1931 until the following April. Occasional specimens of *Clupea* in advanced stages were also taken by the Nova IV in Nova Scotian waters in December and January. On March 5 three eggs of *Hippoglossoides* appeared in the Quoddy region (sta. 5) with five others which may have been either cod or haddock.

The seasonal distribution of eggs and larvae in the bay between April and September (1932) is shown in table XIII. It will be seen that eggs or young of 10 species appeared in April, and until late September no less than five were found

period, April-September, 1932. Larvae unless otherwise indicated

Central area					Bay of Fundy				
8	7	7	8	1	12	12	12	12	11
Apr.	May	June	Aug.	Sept.	Apr.	May	June	Aug.	Sept.
1					2				
1					2				
			1					1	
						2	5		
			10				1	1	
1			1	5	3			629	2683
		1						1	
	4						1		
			16				5	9	3
							10		
			1						
	2	1				5	1	2	
		23	6	4			91	4	
			1						
					1				
2	3				1	8	1		
							11		
	2				1	50	5		
					1				
	11	343	971	1		1	5	50	1

at any time. The largest variety occurred in June and August. Of the forms taken in the inner gulf in 1932 only two larvae, *Leptocephalus conger* and *Merluccius bilinearis* were absent in the collections from the bay.

In 1931 six species were taken in August and September, eggs of *Enchelyopus, Glyptocephalus, Tautogolabrus* and *Merluccius,* and larvae of *Sebastes* and *Clupea.* Monthly collections at one station in the bay over a period of ten months in 1917 yielded eggs of but one species, *Hippoglossoides,* which formed 1.5 per cent of the zooplankton population on April 1, and no larvae.

The seasonal occurrence of eggs and larvae in the inner gulf in the summer of 1932 conforms with previous observations (table XIII). Several species showed a prolongation of the spawning season to the eastward. This was not evident in *Hippoglossoides* whose eggs occurred at the same time (April-May) throughout

the region, but *Gadus-Melanogrammus* eggs, which had largely disappeared in the western area by the end of May, were equally abundant east of Mount Desert in June, and in the bay reached their peak in the latter month. Larvae of several species such as *Pholis, Myoxocephalus, Lumpenus, Glyptocephalus* and *Gadus* were present in the Fundy region a month after they had disappeared in the gulf (table X).

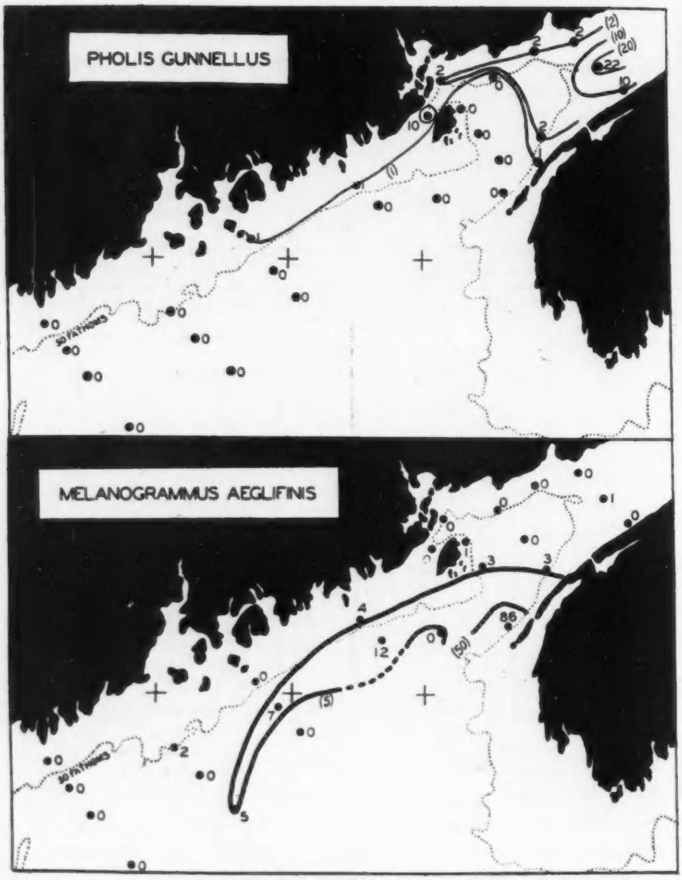


FIGURE 26 (part)

The occurrence of 12 species in the gulf in August 1931 is shown in table XIV. Representing conditions nearer the coast, both eggs and larvae of *Enchelyopus* were very much more abundant and there were larvae of three species, *Cyclopterus, Lophopsetta,* and *Tautogolabrus,* not found at all at the more offshore stations of the next year. Single specimens of *Lophopsetta* and *Tautogolabrus* were taken on Georges bank in September 1932.

Regional variation. The geographical distribution of eggs and larvae in the gulf has been so fully described by Bigelow and Welsh (1925) that little need be added here except to contribute data for 1931-32. Considering the size of the adult stocks of some species, it might appear that the numbers in our collections are surprisingly small. However, previous observers have experienced similar results, particularly in the case of larvae. Eggs have on occasions been taken in

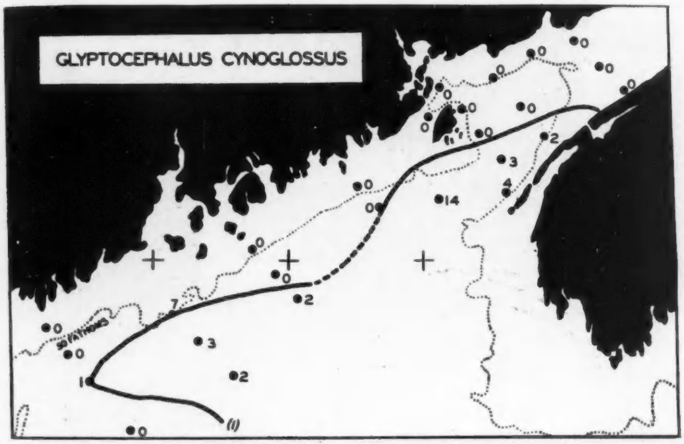


FIGURE 26 (con.). Distribution of larvae of representative species having demersal (upper) and pelagic (lower and right) eggs. Number of individuals per haul.

abundance. In Massachusetts bay in April 1924, 8,148 *Gadus-Melanogrammus* eggs were obtained in a 20 minute foot-net haul, with an average for 20 stations (metre net) of 1038 eggs (Fish 1928, pp. 260 and 268). It seems probable that such rich hauls are to be expected only in the immediate vicinity of limited spawning areas (Bigelow 1926, p. 49). Dispersal of later stages and a consequent reduction in the number per unit of area would inevitably result in the case of species in which the adults occur largely in local concentrations. It is also possible that in the eastern part of the gulf where breeding of such forms as the cod extends over a relatively long period, spawning is never as intense as in the region west of cape Elizabeth. Larvae of two species, *Clupea* and *Sebastes,* one having demersal eggs and the other viviparous, were at times abundant, but our observations did not extend sufficiently far west to include the area where larvae of species having buoyant eggs have been reported most numerous (Bigelow and Welsh 1925, p. 309).

The winter observations in the bay of Fundy, described on p. 260, indicate that pollock were spawning in the New Brunswick waters in November and December, and in early January cod began breeding, first along the Nova Scotian coast. From the distribution during this period it would appear that propagation took place along the two sides of the bay but the eggs did not survive long enough to become

very widely dispersed. This is suggested both by their absence at the offshore stations and the extreme scarcity of advanced stages in all collections in the bay from November to the end of January, a condition according with Huntsman's theory that in the bay of Fundy propagation of most, if not all, species having pelagic eggs is largely unsuccessful (1918, p. 65). In figure 26 it will be seen that at their periods of maximum abundance in the Fundy region in 1932, the young

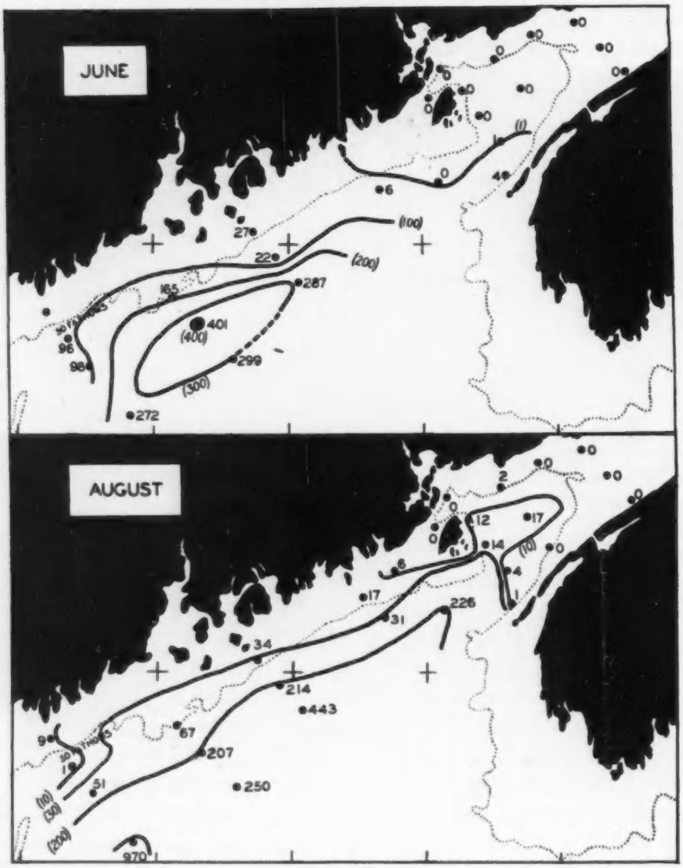


FIGURE 27. Distribution of *Sebastes marinus* larvae in June and August, 1932. Number of individuals per haul.

of *Pholis* (demersal eggs) were concentrated in the inner bay, but there was little evidence of successful local propagation of *Melanogrammus* and *Glyptocephalus* (buoyant eggs) or survival of larvae entering from outside waters.

The regional distribution in the inner gulf and bay during the summer months is shown in tables X and XIII. Of the two most abundant species in the collec-

tions, *Sebastes* and *Clupea,* the former propagates indifferently in both deep and shallow water (Bigelow and Welsh 1925, p. 309) and has been included by Huntsman (1922, p. 16) in the group breeding successfully in the Fundy region. Appearing first in the eastern gulf in May in 1932, larval *Sebastes* soon became widely distributed, but as shown in figure 27, were everywhere found in the greatest abundance at the outermost and deepest stations, particularly in the western area. In the bay only one specimen was taken in 1931 (sta. 10 September), and in 1932, although somewhat more numerous particularly in August, the numbers were relatively small and restricted largely to the deeper water in the central basin (fig. 27). It is quite possible that these may have entered from the gulf, although their absence along the Nova Scotian side, where immigrants are usually most numerous, may be indicative of local propagation.

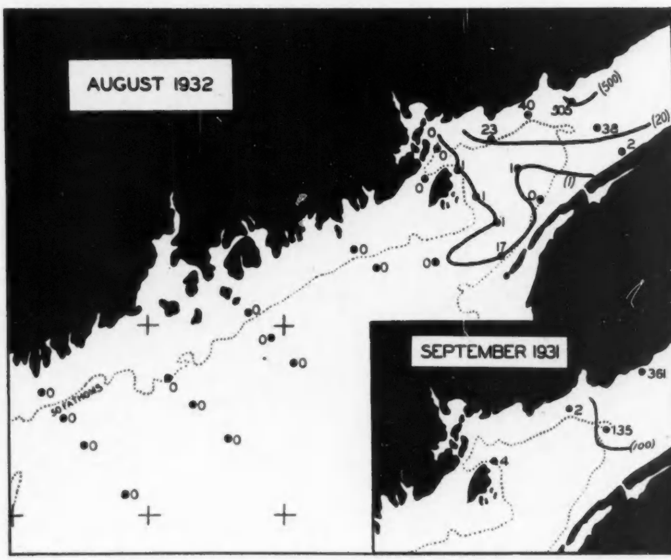


FIGURE 28. Distribution of *Clupea harengus* larvae. Number of individuals per haul.

Clupea harengus spawns in the gulf in summer and autumn, but in the Fundy region, at least in Nova Scotian waters, both spring and autumn spawning takes place (Bigelow and Welsh 1925, p. 95). Centred largely offshore, collections have yielded very few larvae in the gulf during the spawning season. In Gloucester harbour, however, Bigelow and Welsh (1925, p. 100) found a swarm of early larvae from 9 to 11 mm. in late October, and occasional advanced stages (26 to 50 mm.) widespread in the gulf in March and April. Two specimens, 33 mm. in length, were taken in the spring of 1932, both appearing off Mount Desert (sta. 32) on April 22. None were found as far west as this point in the summer or autumn of either year. In the central area in 1931 one individual (9 mm.) was taken at sta. 34 on August 15, and in 1932 five specimens (12-13 mm.) at sta. A1409.

In the bay of Fundy occasional specimens were found in April, but our collections showed little if any evidence of a spring crop. Graham (1936, p. 111) also found that . . . "spring spawning produces no considerable contribution to the herring stock." In New Brunswick waters (sta. 11A and 12) two measuring 43 and 45 mm. appeared on April 18-19 in 1932. On the Nova Scotian side at this time a single individual, 30 mm. in length, was taken at sta. 9 and in zooplankton samples contributed by Mr. Graham from the upper bay (sta. N173, N174, N176) there were six specimens ranging from 23 to 26 mm. (Some larvae may have been removed from the Nova IV samples.) The fact that Bigelow and Welsh (1925, p. 95) found in the gulf members of the autumn stock as small as 26 mm. in April,

TABLE XI. *Clupea harengus.* Length frequency of young in plankton collections, August and September, 1932

1932	Station	Date	Length in mm.			
			7.5-11	12-14	15-19	20-30
August........	6	18	1			
	7	17	1			
	8A	17	17			
	9	19	2			
	10A	19	38			
	11A	19	502	3		
	12	20	39	1		
	13	21	23	1		
	34	15	1			
	36	18		1		
September.....	7	14			2	
	8A	14	1,651			
	9	16	13		9	2
	10A	16		13	7	
	11A	16	1	1		
	12	16		4		
	13	16	47	34	45	23
	36	15	1		6	
	37	15	818	2	1	3

indicates that our specimens were probably of a similar age. These must have left the surface waters soon after this time because none were taken in metre net hauls during May, June or July.

The distribution of larvae in August and September would indicate two distinct sources of the summer-autumn crop, one centred in the inner bay, probably in New Brunswick waters, and the other on the Nova Scotian coast near or outside of the entrance. In 1932, what for purposes of distinction will be called the New Brunswick stock, was found first in mid-August. At this time (fig. 28) propagation appeared to be centred near the coast east of Saint John, where 505 larvae were taken at sta. 11A. As shown in the following table all of these were

very small, rarely exceeding 12 mm. None were found in the outer Quoddy region and very few on the south side of the bay. This crop diminished rapidly and although widespread in the bay in mid-September, their numbers were very sparse (table XI), except at sta. 13 off Pt. Lepreau where 68 specimens, exceeding 15 mm., were taken. It is surprising that so few of this size were found in the outer part of the bay (none in the Quoddy region) and along the adjoining

TABLE XII. *Clupea harengus.* Length frequency of young in plankton collections in 1931

1931	Station	Date	Length in mm.			
			7.5-11	12-14	15-19	20-30
August........	14	18	3			
September.....	6	6			4	
	10	4		129	4	2
	11	4	355		5	1
	12	1	2			
	5	29			2	
	6	30		1	5	
	8A	30			2	
November.....	5	11				1
	6	12				1

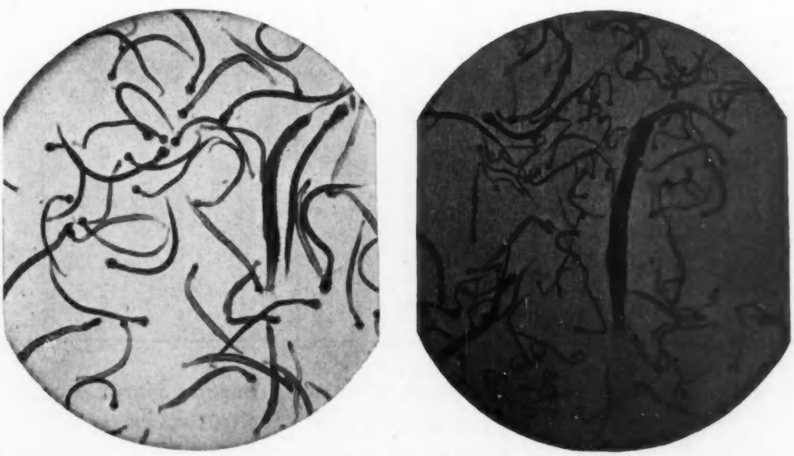


FIGURE 29. *Clupea harengus* taken at stations 10 (left) and 11 (right) on September 4, 1931. Same magnification.

coast of Maine where they would have been expected to drift in a month's time. Indication of the second source of supply became evident in mid-September with an apparent influx of early larvae from outer Nova Scotian waters, 1,651 specimens being taken at sta. 8A (fig. 30). Their small size and absence in collections from the eastern gulf, suggest relatively local origin. Occasional large specimens, 22

to 30 mm., also appeared at this time but their source is uncertain. If they represented the local spring crop it is strange that none were taken in the collections of May, June, July and August.

In 1931 the rather fragmentary records indicate that active spawning of the New Brunswick stock apparently took place somewhat later, and that of the Nova Scotian stock somewhat earlier than in the following year. On September 4, 361 specimens were taken at sta. 11 (13 miles east of cape Spencer), but larvae had not become very greatly distributed westward in New Brunswick waters because just two were found off Saint John (sta. 12) on September 1 and four at sta. 6 on September 6 (fig. 28). Also on September 4 a different size group, comprising

TABLE XIII. Occurrence of fish eggs and young in

	Total region					Western area		
	Apr.	May	June	Aug.	Sept.	Apr.	May	June
Ammodytes americanus larva	T	T				T	T	
Anguilla rostrata elver	T					T		
Argentina silus larva				T				
Asidophoroides monopterygius		T	T					
Brosmius brosme egg			T	T				T
Brosmius brosme larva			.03	T				.1
Clupea harengus larva	T			T	.2			
Enchelyopus cimbrius larva			T	T				T
Enchelyopus cimbrius egg		.04	T		T			T
Enchelyopus-Merluccius egg			.3	.4	.03			.9
Enchelyopus-Merluccius-Urophycis egg			T	.3				T
Gadus callarias egg	T	T						
Gadus callarias larvae		T						
Gadus-Melanogrammus egg	.3	.5	.4			.2	T	T
Gadus-Glyptocephalus egg			T	.04				
Glyptocephalus cynoglossus larva			T	T	T			
Hippoglossoides platessoides egg	.2	.1	T			.1	.03	T
Hippoglossoides platessoides larva			T					
Leptocephalus conger, leptocephalus				T				
Limanda ferruginea egg			T	T				T
Lumpenus lampetraeformis larva		T	T	T				
Merluccius bilinearis larva				T				
Myoxocephalus octodecimspinosus larva	T							
Myoxocephalus scorpius	T	T						
Neoliparis atlanticus larva			T					
Pholis gunnellus larva	T	.01	T					
Pollachius virens larva	T							
Sebastes marinus larva		T	.1	.2	T			.3
Melanogrammus aeglifinus larva			T	T	T			T
Gadus callarias, fry (20-25mm.)			T					T
Urophycis chuss egg		T		T				
Scomber scombrus				T				

135 specimens and believed to represent the Nova Scotian crop, were found in the mid-bay (sta. 10) along the course of the drift from outside waters. Whereas 355 of the 361 larvae at sta. 11 were 7 to 12 mm. in length, all of those at sta. 10 ranged from 11 to 19 mm. with the exception of two having a length of 23 mm. The difference in the average size of the larvae in the two groups can easily be seen in figure 29. Further evidence of different origin is indicated by the volume and character of the zooplankton communities in the two localities. At sta. 10 in the path of the entering drift, with a volume of 470 cc., the population was typical of the open bay. *Calanus finmarchicus* and *Centropages typicus* formed 89.4 per cent and other typical open gulf species like *Pseudocalanus*, *Sagitta*,

Metridia, Tomopteris, Meganyctiphanes eggs, and *Limacina* were present in smaller numbers. At sta. 11 the volume amounted to only 15.5 cc. and, although *Calanus* and *Centropages* formed 45.1 per cent, the remainder of the community was typically neritic containing such species as *Littorina* larvae 6.6 per cent, macruran larvae 6 per cent, *Cancer* zoea 5 per cent, *Crago* larvae 1.8 per cent, *Balanus* nauplii 2 per cent, *Hyas* zoea 0.6 per cent, and several other forms equally characteristic of shallow water.

Evaluation of species. Like adult euphausiids, larval fishes, because of their size, were at times prominent, but numerically they never formed an appreciable factor in the collections except at the above mentioned station in the bay (sta.

1932. Relative percentages in metre net collections

		Central area					Bay of Fundy				
Aug.	Sept.	Apr.	May	June	Aug.	Sept.	Apr.	May	June	Aug.	Sept.
		T					T				
							T				
					T					T	
								T	T		
T					T						
T					T				T	T	
		T			T	T	T			T	.5
				T						T	
			.03	T				.1			T
.3				T	.7				T	.1	.1
.6				T	.2				T	.05	
			T				.01	T			
			T						T		
		.5	.6	.1			.3	.8	1.2		
T					.03				T	.1	
T					T				T	T	T
		.4	.1				.1	.2			
					T				T		
					T						
T										T	
T			T	T				T	T	T	
					T						
							T				
		T					T	T	T		
									T		
			T				T	.03	T		
							T				
.3			T	.1	.2	T		T	T	T	T
				T	T	T			T	T	
T											
T					T						

11) where larval *Clupea* comprised 10.1 per cent of the scanty haul in September 1931. Relative values during the period of greatest abundance in 1932 are shown in table XIII. To this list may be added one specimen of *Anarhichas* (24 mm.) taken by the Nova IV near sta. 10A and several *Cyclopterus* dipped from floating weed in the bay in June. Collections from the outer gulf and Georges bank in September yielded three *Argentina* (33-41 mm. sta. A1411 and A1412), one *Glyptocephalus* (40 mm., sta. A1411), one *Lophopsetta* (4 mm., sta. A1416), one *Tautogolabrus* (14 mm., sta. A1414) and two *Siphostoma* (40 mm., sta. A1414 and 48 mm., sta. A1416).

The following values were obtained in August and September 1931:

TABLE XIV. Occurrence of fish eggs and young in 1931. Relative percentages in metre net collections

Area	Western	Central	Bay of Fundy	
Month	August	August	August	September
Brosmius brosme egg		0.15		
Clupea harengus larva			T	0.8
Cyclopterus lumpus fry	T	T		
Enchelyopus cimbrius egg	5.4	1.2	0.2	T
Enchelyopus larva	T	0.04		
Enchelyopus-Merluccius egg				0.6
Gadus callarias egg	T			
Gadus-Glyptocephalus egg	0.2	0.8	T	0.01
Glyptocephalus cynoglossus egg	T	T		
Glyptocephalus cynoglossus larva	T			
Lophopsetta maculata larva	T			
Lumpenus lampetraeformis larva	T	T		
Neoliparis atlanticus larva	T	T		
Sebastes marinus larva		T		T
Tautogolabrus adspersus egg	0.1	0.2		0.05
Tautogolabrus adspersus larva	T	T		
Urophycis chuss egg	T	T		
Egg. sp. (1.75-1.85 mm. oil glob. 6 mm.)	T	T		

It will be noted that with the exception of *Clupea* and *Sebastes* no larvae were found in the bay of Fundy at this time.

LARVAE OF BENTHONIC INVERTEBRATES

To one familiar with the benthonic fauna south of cape Cod, that of the gulf of Maine contrasts strikingly in two respects, the apparent duration of the breeding seasons, and the relatively few species represented in the collections.

There is a wide variation in the length of the spawning periods exhibited in different species in both regions, but considering the fauna as a whole certain general characteristics are noticeable. Species whose normal range does not extend north of the cape tend to have a very short breeding period, sometimes less than a week, and the pelagic larvae are not commonly taken for more than a month or two at the most. Some of the boreal forms in the gulf of Maine such as *Asterias, Lepidonotus, Crago,* certain of the nereids and members of the genus *Spirontocaris* appeared in offshore collections for only a short time, usually in April or May (table XV), but records from inland waters (table XVIII) showed most of these species still spawning actively in mid-August. It would therefore appear that except at the height of the season many of these species are not present in sufficient numbers beyond the confines of bays to be sampled regularly. Larvae like *Eupagurus, Cancer,* and *Hyas,* occurring in larger numbers outside of the headlands were taken from April to September, particularly in the eastern gulf. In the bay of Fundy the season in some cases may be even longer. There zoea

of *Cancer* occurred from April to December, one species of *Spirontocaris* from July to November, and *Littorina litorea* from April to September.

In species endemic over a wide area, the breeding period may be either equally long throughout the range or somewhat reduced south of cape Cod. Thus *Crago* larvae occur at Woods Hole from May to mid-December and *Eupagurus* from April to November, but *Cancer* zoea appearing in mid-May are rarely found after early August, and *Littorina* larvae only from March until July (Fish 1925, p. 136). Even the more reduced breeding seasons of boreal species south of the cape are relatively long compared with most of the southern ranging species, as indicated in the records for 1922-1923 (Fish 1925, figs. 56 and 59).

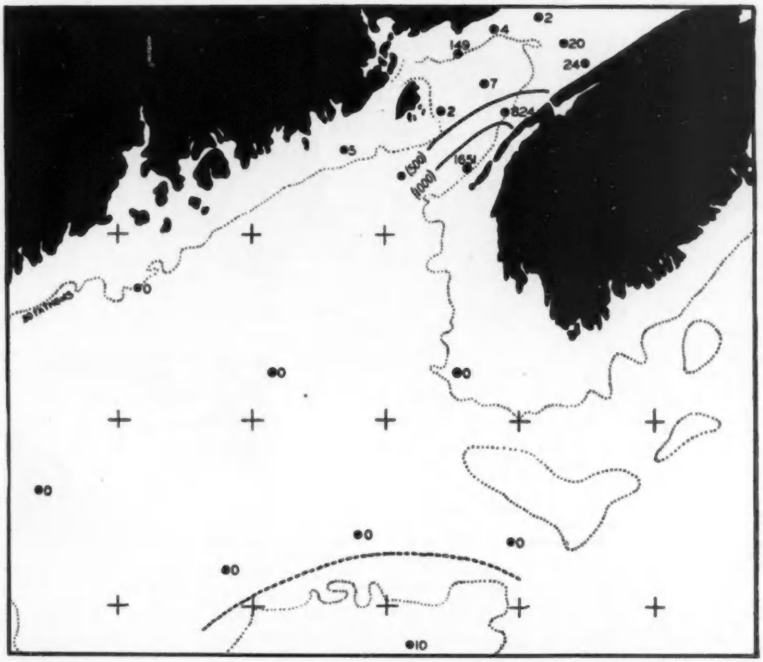


FIGURE 30. Distribution of *Clupea harengus* larvae in September, 1932. Number of individuals per haul.

In some benthonic species, like certain pelagic invertebrates and teleosts, spawning begins first in the western portion of their range and is progressively later to the eastward. Here again, however, there is a wide variation, some showing little or no difference and a few starting considerably earlier in the eastern gulf. *Balanus balanoides* shows a definite delay to the eastward. At Woods Hole nauplii are liberated in early December although they may be found within the shells of the adults several months earlier. In Massachusetts bay Bigelow took nauplii in March and early April, but after April 12 only "cyprids" were found

(1914a, p. 408). Farther east in 1932 small number of nauplii were taken in metre net collections as far west as Casco bay in late April, but as shown in figure 31, the oblique hauls with a smaller net of finer mesh indicate production centred at this time in the outer part of the bay of Fundy and along the west coast of Nova Scotia, with some spawning on Georges bank. The season was evidently almost over west of Mount Desert although small numbers of nauplii were found at 86 per cent of the stations in the western area. In the central and Nova Scotian areas they were taken at all stations, being particularly abundant near the coast as indicated by the following metre net records of April: sta. 30, 47 per cent; sta. 32, 74.9 per cent; sta. 33, 55.6 per cent; sta. 35, 70.5 per cent; sta. 8A, 60.5 per cent.

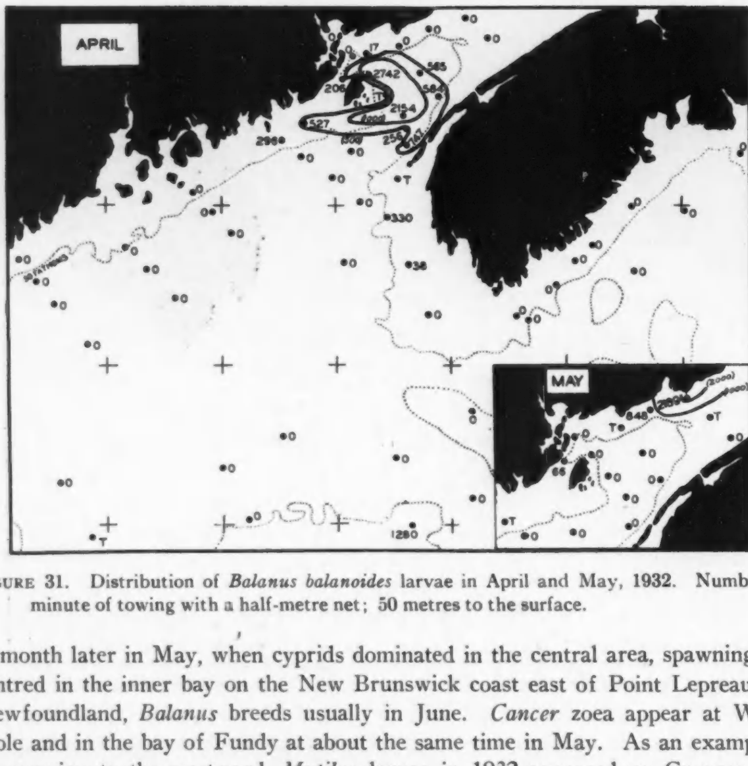


FIGURE 31. Distribution of *Balanus balanoides* larvae in April and May, 1932. Number per minute of towing with a half-metre net; 50 metres to the surface.

A month later in May, when cyprids dominated in the central area, spawning was centred in the inner bay on the New Brunswick coast east of Point Lepreau. In Newfoundland, *Balanus* breeds usually in June. *Cancer* zoea appear at Woods Hole and in the bay of Fundy at about the same time in May. As an example of progression to the westward, *Mytilus* larvae in 1932 appeared on Georges bank and along the southern and western coasts of Nova Scotia in April (p. 275), and in the eastern coastal area of the gulf in May (figs. 32 and 33). At Woods Hole in 1922 and 1923 they were found first in early June.

Why so few larvae of benthonic invertebrates representing such a limited number of species have been taken in the gulf and bay, even within the 100 metre contour, is an open question. The exact number of endemic species in this group

is not known because the region, particularly the offshore area, has been inadequately investigated. The extensive list of species recorded by Kindle and Whittaker (1918, pp. 228-294), however, is ample evidence that the fauna is far richer than the pelagic larvae would indicate. Larvae of but 24 species were found outside of the headlands, during the two years. Of these 15 were Crustacea, four echinoderms, three molluscs, and two annelids. In a similar period at Woods Hole, ten years before, more than 60 species of larvae were taken in plankton nets, there being approximately 36 species of Crustacea, 12 annelids, nine molluscs, one echinoderm, and one chordate. Compared with three species of crab larvae north of cape Cod, 20 were obtained at Woods Hole (Fish 1925, p. 160). The two sets of data are not exactly comparable because the latter collections were

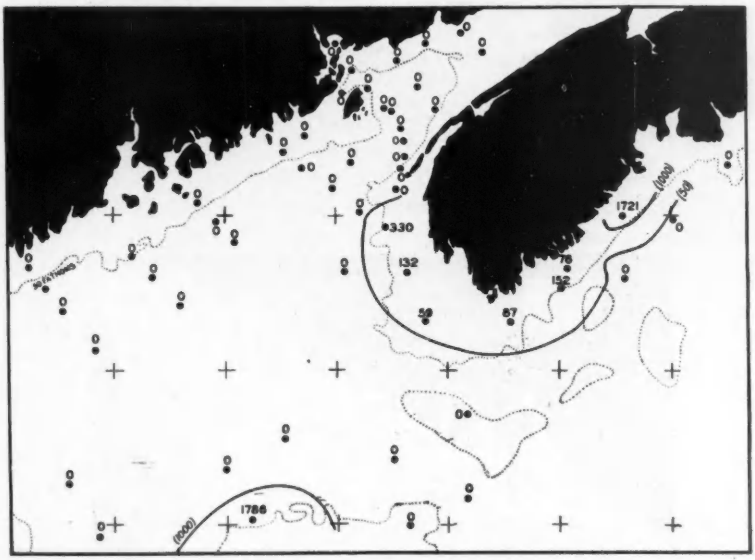


FIGURE 32. Distribution of *Mytilus edulis* larvae in April, 1932. Number per minute of towing with a half-metre net; 50 metres to the surface.

from inland waters. However, lists covering two summers in Frenchmans bay (1929, 1930) and two summers and one winter in Passamaquoddy bay (tables XIX and XXI) are hardly more extensive than those of the open gulf. Similar conditions were also found in 13 bays visited in August 1932, and in records of McMurrich for a period of 12 months in Passamaquoddy bay (p. 286). Investigations of a different type will be necessary to determine whether a larger percentage of boreal benthonic species are viviparous, or have young so advanced upon hatching that like the lobster, *Sclerocrangon,* and some of the mysids, they immediately seek the bottom or remain in surface waters for too short a time to become very widely distributed.

Seasonal variation. The principal breeding periods of benthonic invertebrates in the region occur between April and October. There was no evidence of winter spawning in the bay of Fundy in 1931-32, although advanced larvae of two species of *Spirontocaris* were found in small numbers until early November and a single *Cancer* megalops in December. In the spring of 1932 *Eupagurus* larvae appeared in March, and by late April nine species were widespread in the bay (table XV).

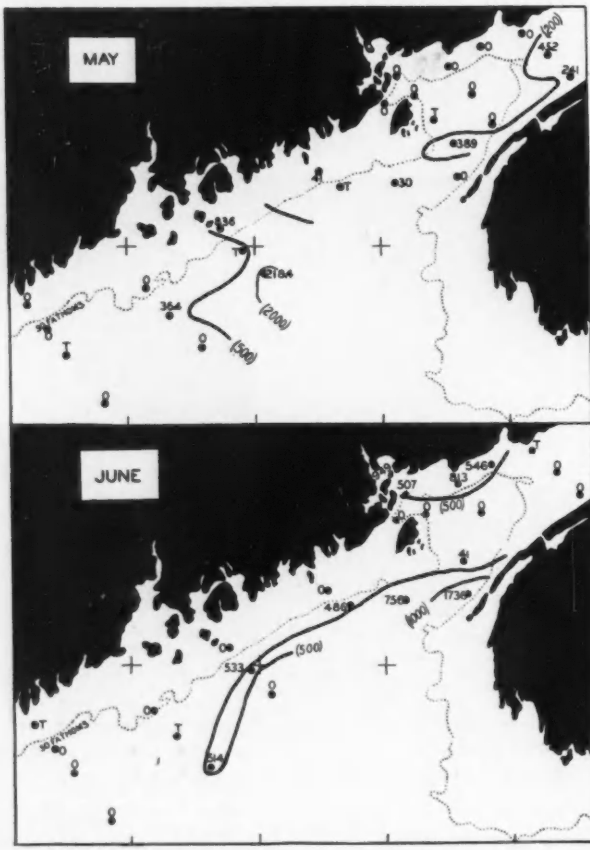


FIGURE 33. Distribution of *Mytilus edulis* larvae in May and June, 1932. Number per minute of towing with a half metre net; 50 metres to the surface.

Both in species and total numbers of larvae the data indicate two maxima in the bay and central area, April-May and August-September. Since the stock appears to be made up largely of the same species in both periods, one might conclude that, as in pelagic species like *Meganyctiphanes,* spring forms in the eastern portion of the region represent migrants from the western gulf, and summer larvae, local production. In the bay of Fundy in 1932 the number of species rose from a

mid-summer low of two (*Littorina* and *Hyas*) at the only station taken in July (sta. 5) to 10 in August, with nine remaining in mid-September. The gradual decline throughout the summer in offshore waters in the western area, almost terminating by the end of August, offered further indication that the spring maximum in 1932 might have been largely of western origin. West of Mount Desert in 1931, however, stations nearer the coast in August yielded 13 species comprising 3.4 per cen of the total zooplankton population (p. 280), and in 1932 records from bays showed production in inland waters almost equally intensive in all areas (table XVIII). It seems probable, therefore, that in some species spring spawning may be restricted to the western area, but an August maximum, at least in neritic waters, occurs throughout the region.

Considering individual species, a few appeared to have relatively short spawning seasons and occurred in but one of the two periods. *Cucumaria,* and two species of *Spirontocaris* were found only in August and September. However as certain others occurring only in spring collections at offshore stations (table XV) were found in bays in August (table XVIII), further records from neritic waters may extend the seasons of the above mentioned.

Balanus nauplii appeared in the spring and again in August and September. A similar condition occurs at Woods Hole, the first stock consisting of *B. balanoides* and the second of *B. crenatus.* Adults along the coast of Maine were not examined, but pending verification, it is suggested that the second and much smaller brood in 1932 were nauplii of *B. crenatus,* a species apparently common throughout the coastal zone.

Regional variation. Too little is known about the distribution of adult benthonic invertebrates in the region to permit a determination of possible sources of young occurring in small numbers offshore. Mount Desert probably marks one of the most important faunal barriers for neritic species within the gulf (p. 284), but the differences in pelagic larvae east and west of this point in 1931 and 1932 appeared to be more quantitative and seasonal than qualitative. With the exception of *Balanus,* previously discussed on page 271, no members of the benthonic group occurred in coarser net collections in sufficient numbers to indicate production centres. The pump and half-metre nets of finer mesh, however, yielded eggs and larvae of two molluscs, one larval cirriped, and eggs of an unknown form, showing definite regional variation which differed strikingly from that of true planktonic species.

The distribution of *Mytilus edulis* larvae from April to June in 1932 is shown in figures 32 and 33. (Eggs were taken only with the pump in July and August). It will be seen that spawning in April was centred on the south coast of Nova Scotia and on Georges bank, with smaller numbers on the western Nova Scotian coast, but apparently the season had not yet begun in the bay or inner gulf. In May production extended into the bay along the Nova Scotian side and as far west as Penoboscot bay, but no larvae were found in New Brunswick waters. By June they appeared on the New Brunswick coast and at offshore stations in the eastern gulf. There was still no evidence of appreciable spawning in the western area,

although larvae from an unknown source were numerous in the drift entering the bay of Fundy. Pump samples in August 1932 indicated that propagation reached a peak at that time east of Mount Desert. In the bay eggs occurred up to 47,460 (sta. 37) and larvae to 25,780 (sta. 7) per cubic metre. The numbers were also

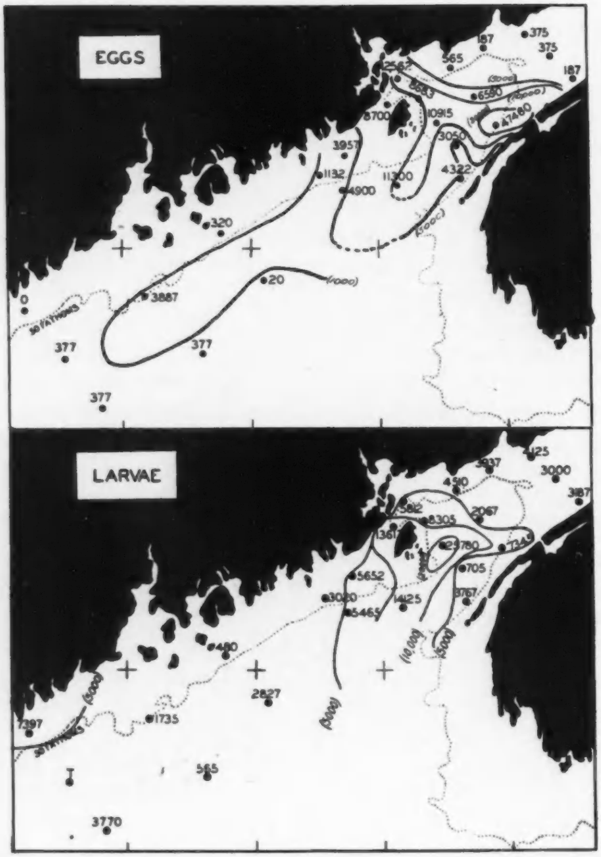


FIGURE 34. Distribution of eggs and larvae of *Mytilus edulis* in August, 1932. Number per cubic metre; 50 metres to the surface.

large in the eastern part of the central area, but in the western area relatively few were found except in the immediate vicinity of Casco bay where 7,397 larvae per cubic metre appeared in the shallowest station (sta. 25A) (fig. 34). The season apparently terminated in September. Records from five stations in the bay of

Fundy (September 14-16) showed no eggs at three (sta. 19, 11A and 13) in the inner part and but 197 and 187 per cubic metre at two (sta. 8A and 36) in the outer part. Larvae were taken at all stations, being most numerous (sta. 8A and 9) along the Nova Scotian coast (1,127 and 1,490 per cubic metre).

In August, 1931, eggs were centred in the central area, amounting to 17,306 per cubic metre at sta. 15, and larvae southwest of Mount Desert where 18,197 per cubic metre were taken at sta. 20 (fig. 35). The western area again appeared

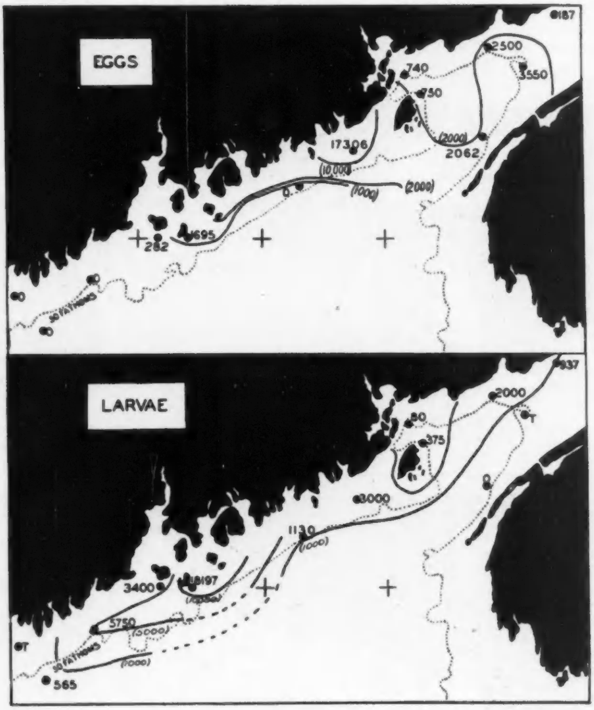


FIGURE 35. Distribution of eggs and larvae of *Mytilus edulis* in August-September, 1931. Number per cubic metre; 50 metres to the surface.

relatively unproductive, for no eggs were taken west of Penobscot bay and larvae decreased rapidly along the course of the drift from this point.

It would thus appear that from April to September in 1932, and at least in August 1931, propagation of *Mytilus* was centred in the eastern gulf and bay. The large numbers in late stages also afford ample evidence that the region offers no unusual restriction to normal development in this species. The reason for the apparent scarcity in the western area remains problematical. It is hardly likely

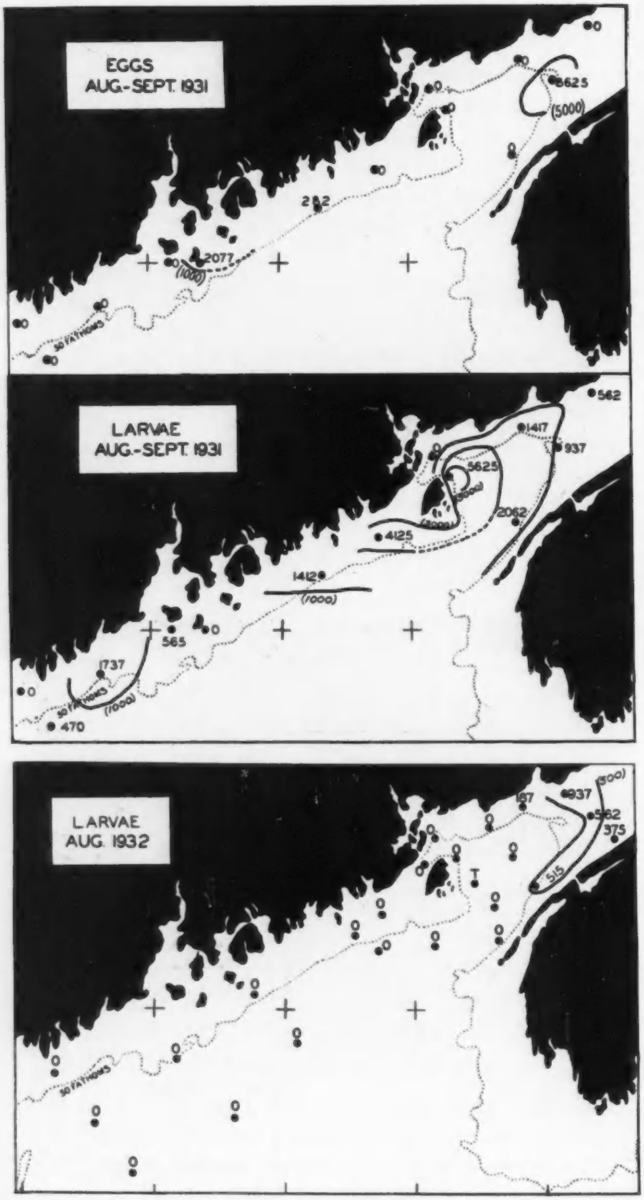


FIGURE 36. Distribution of eggs and larvae of unidentified pelecypod (DE) in August-September, 1931, and in August, 1932. Number per cubic metre. Eggs (937 per cubic metre) were found only at station 13 in 1932.

that their numbers could have been so greatly reduced by enemies or that spawning and the subsequent pelagic period could have passed between cruises, and yet extensive local propagation must take place at some season because adults abound about the entire margin of the gulf. As larvae south of the cape are most numerous in early June (Fish 1925, p. 137), one would expect them in the western sector of the gulf in May (p. 191). No evidence was found there of significant local propagation in 1932, either at the beginning (May 2) or end (May 21) of that month. The matter must await further investigation.

A second species of molluscan larva not positively identified (fig. 37) appeared in the pump samples during August and early September. It may prove to be *Anomia*. In 1931 these larvae were found widespread in the gulf in late August and in the bay in early September, being most abundant about Grand Manan. The distribution of eggs (0.06×0.078 mm.) at this time is shown in figure 36. In 1932 neither eggs nor larvae were taken in the gulf and in the bay the former appeared only at sta. 13 (937 per cm.) in August. Larvae, both in August and September, were restricted largely to the inner bay, in the latter month ranging up to 200 per cubic metre at sta. 9, 11A, and 13, but absent at the outer stations, 8A and 36. Like *Mytilus*, propagation in this species appeared to be centred in the eastern part of the region with smallest returns in the western area off Casco bay.

Two species appeared to originate in Nova Scotian waters. One, a cirriped larva known in the eastern Atlantic as Hensen's nauplius (Hoek 1909), was found in April off Halifax and along the west coast of Nova Scotia into the bay of Fundy. None were taken in the inner bay, or at 21 stations in the inner and outer gulf (fig. 38). In May a few appeared at one station near the mouth of the bay (sta. 34) and at one in New Brunswick waters (sta. 13). The second species, represented by eggs, (fig. 39) appeared only in April and could not be identified. It was taken in six hauls off the south coast and in one off the west coast of Nova Scotia. Its total absence elsewhere in the gulf and bay would suggest a movement into the region from the eastward, in the drift past cape Sable known to occur at this season (p. 202).

Evaluation of species. Local swarms of larvae of bottom species are frequently encountered inside of the headlands during the spring and summer, but in the open gulf and bay, except for a short period of two months, April and May, they formed a relatively insignificant part of the pelagic population in 1932. In the western area where their appearance coincides with vernal augmentation of dominant zooplankton species, they were never found exceeding 5 per cent (table V). Progressing eastward they became increasingly important at this time because of the seasonal delay in zooplankton response in the central and New Brunswick areas. In April, due largely to *Balanus* propagation, they formed 39.6 per cent in the central area and 17.6 per cent in the bay, with much higher values at some of the individual shallow stations. By May, with the passing of barnacle larvae, the values declined to 0.3 per cent in the western area, 6.0 per cent in the central

area, and 8.1 per cent in the bay of Fundy. Thereafter values exceeding 0.5 per cent were found only in the bay, and here the August maximum amounted to only 3.3 per cent. It can be concluded with reasonable certainty, therefore, that pelagic larvae of benthonic species are rarely of significance in the natural economy of the open gulf, and only slightly more important outside of the headlands in the bay of Fundy.

Not all of the larvae in the collections have been identified, particularly among the annelids, molluscs, and macrurans. Nine members of the latter group have not been determined. However, it is probable that when a more detailed study

TABLE XV. Larvae of benthonic invertebrates.

	Total region					Western area		
1932	Apr.	May	June	Aug.	Sept.	Apr.	May	June
Balanus balanoides larva	18.0	3.8				.4	.02	
Crago septemspinosus larva		.02						
Other macrura:								
Macruran A					T			
Macruran B				T	T			
Macruran B'				.07	.03			
Macruran C				.8	.2			
Macruran D	.2	.1	T			.03	T	T
Macruran E	.1	.7		T		T	T	
Macruran F	.05	.03				.06	.1	
Macruran W				T				
Eupagurus sp.	.5	.7	.4	.1	.03	.05	T	.03
Cancer sp.		T	T	.03	.1			T
Hyas coarctatus	.1	.05	.3	.7	.1	T		.2
Ensis directus (Juvenile)					T			
Lepidonotus squamatus		.03						
Nereid larva		.2						
Asterias vulgaris	.01							
Ophiopluteus	1.3	.07		T		3.9	.2	
Cucumaria frondosa	.02	.2	T			T	T	T

can be made, the identity of several of these will be revealed, because the larvae of the more common species in the region have already been described from European waters.

Between October and March occasional larvae of four species of benthonic invertebrates, described on page 274 were taken in the bay of Fundy. The relative numerical values in the different areas between April and September in 1932 are shown in table XV. Crustácea comprised the greater part of this group at all times.

In 1931 the results shown in table XVI were obtained.

Two of these species, *Carcinides maenas* and *Strongylocentrotus drobachiensis* did not appear in the collections of the following year.

In 1917, at one station in the bay of Fundy, (sta. 5) no members of this group were found in January, February, March, August, September, and December. The records for the other months represented in the collections were as follows: April, macruran C. 3.1 per cent; May, *Balanus* 0.6 per cent, macruran C. 1.1 per cent; June, *Balanus* T; July, *Eupagurus* sp. 1.1 per cent; *Hyas* 1.1 per cent; October, *Cancer* 0.3 per cent; November, *Hyas* 0.4 per cent.

In outer areas in 1932, no larvae were found at four stations off the south

coast of Nova Scotia in January, but in April eight stations in the same locality yielded, macruran C. 0.4 per cent, *Eupagurus* 0.2 per cent and traces of *Balanus* and macruran J. In May traces of macruran F. and an *Ophiopluteus* larva were taken in the central basin of the gulf, and *Balanus* (1.0%) and macruran C. (T) in the eastern channel. None appeared at one station on Browns bank. In September but one species, *Cancer* (0.9%) was found at four stations in the outer gulf, and but two species, *Eupagurus* (0.3%) and macruran A. (T), on Georges bank. No members of this group appeared in one haul off the west coast of Nova Scotia at this time (sta. A1410).

Relative percentages in metre net collections, 1932

		Central area					Bay of Fundy				
Aug.	Sept.	Apr.	May	June	Aug.	Sept.	Apr.	May	June	Aug.	Sept.
		38.6	5.0				16.2	5.3			
			.03					.03			
											T
T					T					T	T
					T					.02	.1
T	T				.2	T		T		1.5	.6
		.04	.4	T			.4	.1	T		
		.3	.1		T		.1	.1		T	
		.1	.01				T	T	T		
										T	
T	T	.5	.2	.1	.2		.8	1.3	.7	.2	.1
T					.05			T		.05	.4
.06		T	T	T	.1		.2	.1	.5	1.4	.3
											T
			T					.1			
								.5			
		.02									
							.01	T		T	
		.06	.1	T			T	.5	T		

TABLE XVI. Larvae of benthonic invertebrates in zooplankton collections in 1931. Relative percentages

Area	Western	Central	Bay of Fundy
Month	August	August	September
Balanus crenatus	T	3.7	0.3
Crago septemspinosus	0.3	0.2	
Macruran A	T		
Macruran B	0.1	0.03	
Macruran C	0.8	T	0.7
Eupagurus sp.	0.3	T	T
Cancer irroratus	1.5	0.1	
Carcinides maenas	T		
Hyas coarctatus	T	T	0.1
Ophiopluteus larva	T	T	
Strongylocentrotus	0.01		0.01
Littorina litorea	0.02		
Mytilus edulis	0.35	0.4	

BENTHONIC INVERTEBRATES

Too little consideration has been given to the importance, in the natural economy of the region, of the very rich fauna on or associated with the bottom. In the inner gulf and bay mysids, Cumacea, caprellids, gammarids, ostracods, and benthonic copepods, together with many less abundant forms were regularly taken whenever the bottom was sampled. Unfortunately no quantitative data are available for these waters and such studies could not be included in the present program.

Adult benthonic forms appearing in the collections may be grouped in two classes, accidental and free-swimming. Most were accidental, and had either been passively transported into the upper levels by violent current action or entered nets coming in contact with the bottom. The increasingly large numbers of both species and individuals encountered eastward from Mount Desert, with maximum

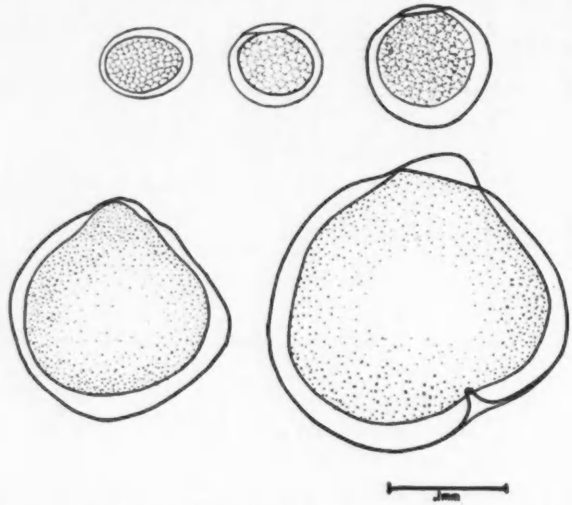


FIGURE 37. Egg and early developmental stages of an unidentified pelecypod (DE), possibly *Anomia aculeata*.

numbers in the bay of Fundy, are indicative of turbulence. Some in the central area and almost all of those in the western area were scraped from the bottom as evidenced by sand or mud in the nets. A relatively few species, the most common of which were members of the genus *Idothea,* were taken clinging to weed or other floating objects at the surface. This class of accidental forms should probably not be included with zooplankton, but the second, consisting of benthonic species free-swimming during their breeding season, can be correctly considered a part of the pelagic population.

The two groups can usually be distinguished in plankton collections. Excluding those found on drifting objects, accidental forms are most frequently represented by several and often many species in a haul, particularly when the

bottom has been touched. Breeding forms most commonly occur as single species in relatively large numbers. Neritic mysids, amphipods, annelids, and on rare occasions Cumacea have been found free-swimming in the western Atlantic. At Woods Hole swarms of amphipods (*Batea secunda, Gammarus annulatus, Monoculodes edwardsi, Stonothoë cypris,* and *Calliopius laeviusculus*), mysids (*Neomysis americana*), and annelids (*Nereis virens, N. limbata, N. pelagica, Platynereis megalops* and several species of the genus *Autolytus*), were observed in 1922 and 1923 (Fish 1925, pp. 130, 149, and 152). Such concentrations are rarely found beyond the shallow coastal zone, although *Autolytus* was at times taken well offshore in the gulf, and one species, *Calliopius,* has been reported in the vicinity of the Gulf Stream (Fish 1925, p. 150).

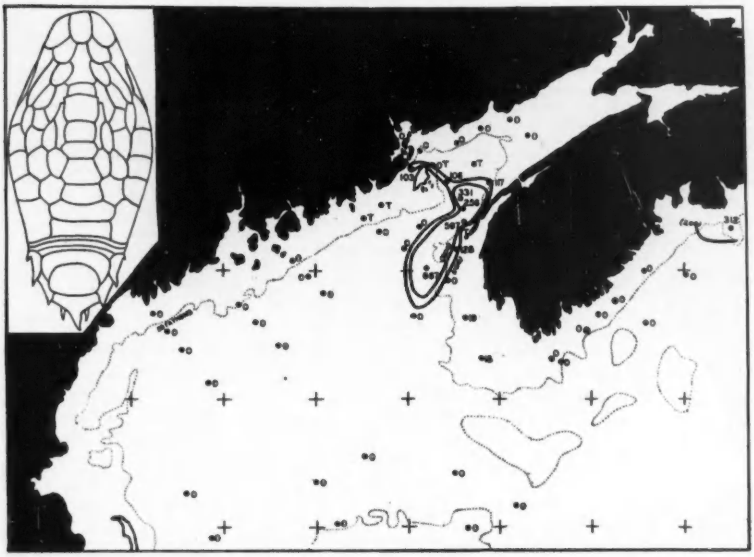


FIGURE 38. Distribution of Hensen's cirriped nauplius IV in April, 1932.

Thirty-eight species of benthonic invertebrates were found in the offshore collections of two years, 23 in 1931, and 28 in 1932. These comprised two macrurans, two mysids, ten Cumacea, eight amphipods, five isopods, three copepods, one mollusc, one cephalopod and six annelids. As previously mentioned (p. 273), considering the number of species reported from the bay of Fundy alone (Kindle and Whittaker 1918), it is evident that the present material is not indicative of the composition or abundance of the bottom fauna. (When sand or mud was observed in the sample, the haul was repeated. Had such collections been recorded the list would have included many more species.) It is included here merely to show that although certain species are at times pelagic, they apparently never form an appreciable part of the zooplankton population of the open gulf and bay.

Our data are also too sparse to indicate regional variation, and previous records afford little on the ranges of benthonic species. In the inner gulf, Mount Desert, where the cold drift from the eastward veers offshore, probably forms an important faunal barrier due to differences in temperature and turbulence (p. 275). Possibly other barriers, less marked perhaps and affecting fewer species, may also occur. Cape Ann and perhaps cape Elizabeth might be expected to form minor barriers, and differences in the benthonic fauna on the two sides of the bay of Fundy are observable.

Seasonal variation was evident in a few species free-swimming during the spawning period. Mature adults of *Nereis virens* were found in small numbers in the central area and also off the west and south coasts of Nova Scotia in April

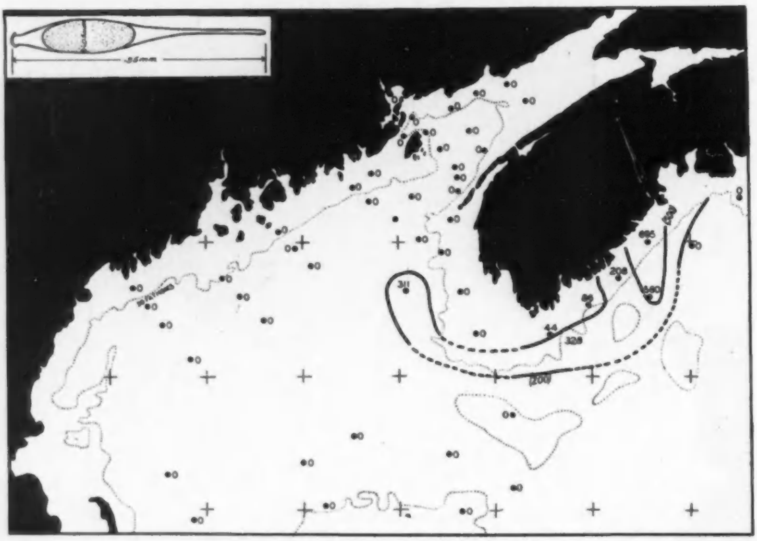


FIGURE 39. Distribution of an unidentified egg (Q) in April, 1932.

1932. A month later they appeared in collections from the bay of Fundy. Of four species of *Autolytus*, three (*A. alexandri*, *A. cornutus*, and *A. varians*) occurred at the surface only in April and May, but a fourth, *A. longisetosus*, although most abundant in April (0.2% in the bay), was widespread over a much longer period: August (1931), January, April, May, June, and September (1932). *Neomysis americana* was found at the surface in April only. Considered by areas the pelagic periods appear, in some instances, to occur later and be more extended in the bay of Fundy. None were found in the western area after April, and in the central area after May.

At Woods Hole the breeding seasons tend to begin earlier than north of the cape, the largest swarms of breeding amphipods occurring during the winter

months (Fish 1925, p. 149), *Neomysis* from December to April (p. 152), *Nereis virens* in April (p. 131), and in the case of *Autolytus,* egg bearing adults of one or more species have been taken in every month of the year (fig. 33, p. 131).

Amphipods and cumaceans which may have been pelagic were taken in small numbers in the central area and bay in 1932, but occurring in turbulent waters together with obviously accidental forms, they could not be distinguished with certainty as such, although in some instances they were carrying eggs.

Evaluation of species. The relatively insignificant numbers of benthonic invertebrates in the zooplankton at all times is indicated by the fact that, in the bay of Fundy where the largest hauls were obtained, the values did not exceed 0.3 per cent at the periods of greatest abundance, April and June (tables IV, V and VI). The three most numerous forms in collections from the latter area were *Autolytus longisetosus* (0.2% in April). *Dulichia porrecta* (0.2% in June) and *Neomysis americana* (0.1% in April). All other species occurred everywhere as traces. The following species were taken during the two years:

TABLE XVII. Occurrence of benthonic invertebrates in zooplankton collections. Relative percentages in metre net hauls

Area	Gulf		Bay
Year	1931	1932	1931-1932
Crago septemspinosus			T
Pandalus montagui		T	
Erythrops erythropthalma	0.05	T	T
Neomysis americana	0.02		T
Campylapsis rubicunda	T		
Diastylis abbreviatus	T		
Diastylis polita		T	
Diastylis quadrispinosa		T	
Diastylis sculpta	T	T	T
Eudorella hispida		T	
Lamprops fuscata	T		
Leptostylis longimana	T		
Leucon nasicoides			T
Petalosarsia declivis			T
Anonyx nujax		T	
Calliopius laevisculus	T	T	T
Corophium cylindricum	T	T	T
Dulichia porrecta	T		T
Monoculodes sp.	T		
Podocerus sp.		T	
Stegocephalus inflatus	T		
Stenothoë cypris	T		T
Aeginella longicornis			T
Caprella linearis	T		
Cyathura brachiata	T	T	
Idothea baltica		T	
Munna kroyeri	T	T	

TABLE XVII—*Continued*

Area	Gulf		Bay
Year	1931	1932	1931-1932
Harpacticus chelifer	T		T
Harpacticus uniremis			T
Tisbe furcata			T
Dentalium entale	T		
Rossia glaucopis	T		
Autolytus alexandri			T
Autolytus cornutus			T
Autolytus longisetosus	T	T	T
Autolytus varians			T
Nereis virens		T	T
Sternaspis fossor	T		
Floating hydroids		T	T

INLAND WATERS

Zooplankton collections were obtained in sixteen bays in the gulf and Fundy regions in August and September 1932 (fig. 2). Eight Petersen trawl samples from St. Mary bay, taken by the Nova IV in December, January, and April (1931-32) are not comparable quantitatively with the plankton-net hauls, but indicate the character of the winter population in that area. Also available are unpublished data obtained by the senior author in inland waters between cape Ann and Mount Desert in August and September 1924, and weekly observations during two summers (1929 and 1930) in Frenchmans bay, with occasional records from Blue Hill and Penobscot bays.

Material from Passamaquoddy bay and the outer Quoddy region (sta. 5) includes routine collections during the period, July 1931 to September 1932 (fig. 40), and occasional data from the entering passages to Passamaquoddy bay in August and September 1931 and September 1932. From former years records were obtained of 33 hauls in the bay between November 23, 1915, and October 9, 1916, compiled by Dr. J. P. McMurrich, and 10 samples taken by the Biological Board of Canada between March 19 and December 19, 1917.

COMPARISON OF INLAND WATERS OF THE GULF AND BAY OF FUNDY

QUANTITATIVE DISTRIBUTION

Observations in August 1932 extended from Casco bay to Pt. Lepreau (sta. A-M), with two stations on the Nova Scotian coast, in St. Mary bay (sta. J) and Annapolis basin (sta. K). The neritic population at this time showed the same quantitative decline to the eastward as the offshore population (fig. 41), the highest value (151 cc.) being obtained in Casco bay. In the vicinity of Penobscot bay the volume was 93 cc., in Frenchmans bay 53 cc., off Pleasant bay 12 cc., and Machias bay 9 cc.

Quantitatively the population in neritic waters throughout the region was

smaller than in neighbouring offshore areas, a condition also observed by Bigelow (1926, p. 85). During the summers of 1931 and 1932 volumes never failed to decrease upon approaching the coast and within bays the quantities were small compared with those in the vicinity of the entrances. Thus upon entering Penobscot bay in August the volume decreased from 93 cc. to 44 cc., and in Frenchmans bay from 53 cc. to 8 cc. No station was made off Blue Hill bay, but

FIGURE 40. Zooplankton stations in the vicinity of Passamaquoddy bay.

one between Swans island and Bass harbour in the bay proper, yielding only 19 cc., indicated conditions comparable with the others. In the bay of Fundy volumes declined from 46.9 cc. in the outer Quoddy region (sta. 5) to 20 cc. in Passamaquoddy bay (fig. 41), and from 44 cc. at sta. M9 to 10.5, 9.3, and 6.5 cc. at stations M10-12 in Maces bay (fig. 40).

COMPOSITION OF THE POPULATION

Records from Frenchmans bay in 1929 and 1930, and in Passamaquoddy bay in 1931 indicate propagation of neritic zooplankton to be at a maximum in mid-August when the present collections were made.

Considering first the ecological groups comprising the population, all but one (southern migrants) of those found in the open gulf were represented in inland waters, although as shown in table XVIII northern migrants did not appear west of Mount Desert at this time. Physical conditions, particularly depth, temperature, and stability, vary greatly in different localities and result in corresponding variations in the character of the zooplankton, even in neighbouring bays (tables XVIII and XIX). Areas having marked thermal stratification were found to contain the richest summer populations, with boreal offshore forms concentrated by day in the cold bottom water, neritic species at intermediate depths, and eggs and larvae in the warm upper layer.

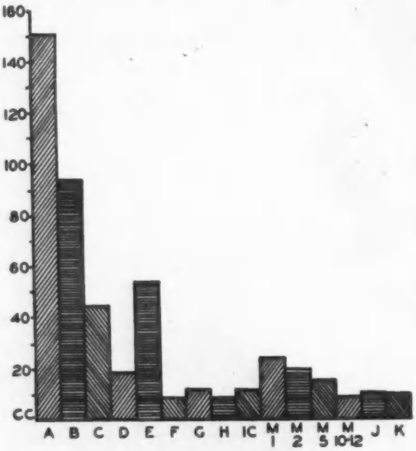


FIGURE 41. Comparative volumes (displacement) at neritic stations in August 13-19, 1932. Twenty minute oblique metre net hauls.

Open gulf species form a considerable part of the stock throughout the year, but as in the outer coastal zone, regional differences are greatest in summer. At that time in the stable western area cold water persists in the lower levels of the deeper bays, and here members of this group remain in relatively large numbers. At all stations west of Mount Desert in August 1932 they exceeded 60 per cent of the total population except in the shallower part of Penobscot bay, and there the values quickly rose from 26.2 to 83.2 per cent at the entrance. In Frenchmans bay turbulence reduces the temperatures in the upper levels, but does not seriously affect the bottom water, which warms very slowly during the late summer. There were therefore, relatively few larvae of offshore species (p. 311) but adults even in the inner part near Ironbound island on August 15-16 amounted to 79.4 per

cent, almost as high as off the entrance (83.6%). Passing eastward from Pleasant bay (sta. G) there was a marked decline in offshore species in the very turbulent central and New Brunswick areas. In Machias bay (sta. H), with a surface temperature of 10.5°C. and a vertical gradient of less than 1°C. in 40 metres, they formed only 31 per cent, and in Passamaquoddy bay 27 per cent. Along the New Brunswick coast, except for local swarms of *Meganyctiphanes* eggs encountered off the L'Etang river (sta. M1) and at some of the stations in Maces bay (sta. M5 and M12), the boreal stock was comparable with Passamaquoddy and Machias bays, totalling 14 per cent in Mink bay (sta. M10) and 32 per cent in Lepreau bay (sta. M11). Representative of very shallow areas where the entire water mass responds to summer warming, members of this group in St. Mary bay (sta. J) and Annapolis basin (sta. K) were very sparse, as indicated in table XVIII.

TABLE XVIII. Composition of the zooplankton population in neritic waters. Relative percentages

Region	Western area					Central area							New Brunswick area					Nova Scotia	
Station	A	B	C	D		E	F				G	H	1C	M1	M5	M10	M11	J	K
Year	1932	1932	1929	1932	1929	1932	1932	1929	1930	1932									
Date - August	13	14	20	14	20	14	15	3	16	9	15	15	21	15	17	18	18	16	19
Open gulf species	82.3	83.2	55.8	26.2	44.7	61.6	83.6	41.6	60.2	79.4	65.1	31.0	27.0	92.4	98.9	14.0	32.7	24.4	9.9
Northern migrants							T		T				T	.3					
Neritic zooplankton	6.4	14.8	2.5	55.8	6.4	32.2	11.0	37.2	36.4	5.6	13.8	41.5	68.2	7.2	.7	80.4	66.5	42.2	61.8
Fish eggs & larvae	8.1	1.0	38.8	.6	44.6	3.4	3.0	15.2	T	11.4	9.5	1.5	1.0	.2	.5	1.8	.7	4.4	2.5
Larvae of benthonic invertebrates	3.1	.8	2.8	17.4	3.4	2.5	2.7	5.9	3.2	4.0	11.9	25.5	3.6	.1	.2	3.7	T	28.4	26.0
Benthonic invertebrates			T			T			T		T	.4				T	T	.6	

Neritic species and larvae of benthonic invertebrates attained their highest values in shallow enclosed bays such as Penobscot (73.2%), St. Mary (70.6%), and Annapolis basin (87.8%), and in turbulent waters like Machias bay (67%), Mink bay (85.1%), and Lepreau bay (66.5%). It would appear, however, that these two groups reproduce successfully in bays throughout the region, the relatively large percentages in shoal and turbulent waters being due for the most part to the decrease in offshore species, as indicated clearly by the smaller volumes in those areas.

Pelagic fish eggs and larvae were least abundant in New Brunswick waters (0.8% average) and the eastern part of the central area (1.5%). They increased rapidly to the westward, forming 9.5 per cent in Pleasant bay and 11.4 per cent in Frenchmans bay. The actual numbers were even larger farther west, but due to the much richer invertebrate population, the average percentage for the four stations, A to D, amounted only to 3.3 per cent.

Former August records show wide variations from year to year in some of the bays (table XIX). In almost every case this resulted from differences in the propagation of a very few species. For example, in Penobscot bay in 1929 small numbers of six neritic plankton species totalled 2.9 per cent with no one exceeding 0.8 per cent, while in 1932 two species, *Phialidium* and *Podon leuckarti,* amounted to 54 per cent. In Blue Hill bay the latter species in 1932 formed 28.4 per cent of the total of 32.2 per cent for the group, but was absent in 1929. In French-

mans bay, although *Podon polyphemoides* was not found in 1932, it swarmed both in 1929 (59% on August 3) and 1930 (73.7% on August 7, and 69.6% on August 16). Similarly the large percentages of fish eggs and larvae in 1929 in Penobscot bay (38.8%) and Blue Hill bay (44.6%) consisted almost entirely of *Merluccius* and *Tautogolabrus* which appeared as traces in 1932. It is probable that in most instances these records do not indicate annual quantitative differences, but rather

TABLE XIX. Evaluation of species comprising the

Year	1932							
Area	Western				Central			
Station	A	B	C	D	E	F	G	H
August	13	14	14	14	15	9	15	15
Calamus finmarchicus	14.3	39.2	4.2	7.3	35.6	3.5	33.8	9.3
Metridia lucens	23.6	6.0	.6	2.1	23.8	3.5	10.3	1.1
Pseudocalanus minutus	2.0	.2	3.0	4.7	10.7	10.9	2.8	17.4
Centropages typicus	1.0	8.1		.4	.3		2.4	
Meganyctiphanes egg		21.8			4.2	46.2	.4	.7
M. norvegica larva and adult	40.6	6.3	2.4	2.2	2.1	1.8	2.4	
Sagitta elegans	T	.2	11.8	19.0	2.4	9.6		T
Oikopleura labradoriensis				.9	T		2.8	1.1
Fritillaria borealis		.5	.6		3.9	3.0	10.2	.7
Temora longicornis	.2		.6	13.8		.9	T	.7
Limacina retroversa	.6		2.4	8.2				
Thysanoessa, young	T	.5	.6	3.0	.6	T		
Aglantha digitalis	T	.2			T		T	
Acartia bifilosa								
Acartia clausi								2.8
Acartia longiremis			.6	.4		.4	.4	T
Centropages hamatus			T					
Eurytemora herdmani		.2	T	3.4	.3			.7
Tortanus discaudatus	.4		T	T		1.3	2.8	8.5
Evadne nordmanni	.2	12.5			1.5		3.5	
Podon leuckarti			19.1	28.4	8.6	3.5	6.7	28.8
Podon polyphemoides								
Obelia sp.	5.4		1.2	T	.6		.4	.7
Phialidium languidum	.4	2.1	34.9		T	.4	T	
Enchelyopus-Merluccius egg	7.1	.5	.6	3.0	1.2	11.4	7.9	1.1
Gadus-Glyptocephalus egg	.6	.5		T	1.5	T		T
Glyptocephalus cynoglossus larva	.4	T			.3		1.6	
Limanda ferruginea egg		T	T	.4	T		T	.4
Tautogolabrus adspersus egg								
Calliopius laevisculus								
Balanus crenatus nauplius				.4		.9	3.9	6.7
Crago septemspinosus larva								
Macruran B larva	.9			.4	.9	2.2	2.8	9.9
Macruran C larva		T	8.4	1.3			.8	
Eupagurus sp. larva	T		T					1.8
Cancer irroratus zoea	2.2	.8	5.4	.4	.9	.9	2.0	1.8
Lepidonotus squamatus larva								
Asterias vulgaris larva			3.6		.3			
Mytilus edulis larva								
Littorina litorea egg and larva							2.4	5.3

variations in the period of the maxima, as in the case of *Acartia* in Passamaquoddy bay (p. 294). However, common neritic species have frequently remained sparse and sometimes apparently absent in certain years. The above mentioned form, *P. polyphemoides*, was widespread in the western and central areas in two former years, but in 1932 it was not taken anywhere in the region. Another member of the genus, *P. leuckarti*, did not occur in 33 hauls in July and August in French-

mans bay in 1929 although it proved abundant at that season in 1930 and 1932. A third species, *P. intermedius,* was observed only at Boothbay harbour, where on August 31, 1932, a swarm was so dense that the water appeared cloudy and more than three ounces (ca. 80 cc.) were taken in a single dip with a hand net. This form occurs regularly south of cape Cod in summer (Fish 1925, p. 139) and has been reported once from St. Andrews (MacDonald 1912) but did not

zooplankton in certain inland areas. Relative percentages

							1929			1930	1931
New Brunswick					Nova Scotia		Western		Central		N.B.
1C	M1	M5	M10	M11	J	K	C	D	F	F	1c
21	15	17	18	18	16	19	20	20	3	16	13
3.7	7.3	.9	2.1	5.4	1.2	1.2	2.8		.4	9.4	5.4
.2	.4		.6	.7							
9.5	4.0	1.7	5.8	16.8	T	8.7	18.5	7.8	.8	39.2	1.6
5.1	T	.7	2.8	2.7	T						
1.7	80.7	95.6	.9	.7					36.6	4.2	
1.5	T		.3		.6					T	
T		T			T		1.5	.9	.4	.1	.5
						T					
2.2		T	1.5	6.4	21.4						
2.9				T	T	T	33.0	35.4	3.4	6.9	.4
.2											
					1.2	T	T				
								3.3	2.3		
33.1	1.3		9.2	.7	6.2	49.5				.3	51.7
							.8		.8	11.6	
					10.7	2.5					
5.3	.3		T			4.9	.5		.8	.1	1.6
22.8	2.0		T	.7	12.9	4.9	T			T	7.8
3.6	2.0	.7	50.1	63.4	.6		.5	.6	3.8	.8	
2.2	1.5		20.8	1.7						.8	
				T			.5	2.5	29.5	22.8	
1.2			.3	T	11.8	T				T	
	.1						T	T			
1.0	.1	.5	1.5	.7	1.1		19.4	7.6			1.6
T	.1		.3	T		T	5.5		15.2	T	
				T	3.3	2.5					
							13.9	37.0		T	
											7.4
						1.2	T				
							2.8	T	.4	1.2	15.8
1.9	T		.6		4.5	8.7					
.5				T							2.6
.2									T		2.6
.5	T		2.8	T	2.5	2.5		3.4	.4	T	T
						2.5	T		T		
								T	.7		
							T	T	3.7	2.0	
	T		.3		21.4	11.1		T	T		

appear in collections of six years (1916, 1917, 1924, 1929-31) from inland waters of the gulf and Fundy regions.

Although varying in season distribution in different bays and to some extent in the same locality from year to year, the above records and others which may be cited indicate that the more important neritic zooplankton species have but one major propagation period, in summer or autumn. The swarms of individual

species frequently encountered at such times are usually of rather limited duration and geographical range. *Evadne nordmanni* in 1924 was found swarming in Boothbay harbour on September 3 and in Northeast harbour on September 19. In 1929 it formed up to 69.6 per cent of the population at a few stations in Frenchmans bay on July 23, and 37.8 per cent at one station in Penobscot bay on August 23, 1930. In 1932 the only swarms noted were at sta. M10 (50.1%) and sta. M11 (63.4%) in Maces bay on August 18. Another species, *Eurytemora herdmani,* formed over 80 per cent of the population in Somes sound (Frenchmans bay) on September 19, 1924, and 46.4 per cent in Passamaquoddy bay on September 23, 1932. Other swarms observed include *Acartia bifilosa* (79% on July 16, 1929, and 64.8% on July 14, 1930), *A. longiremis* (41.3% on August 12, 1930) in Frenchmans bay, and *Tortanus discaudatus* in Passamaquoddy bay (25.3% on October 15, 1931, 22.8% on August 21, 1932, and 66.8% in October 1917). A swarm of *Aurelia aurita* planulae was observed off Bluff island in Casco bay on August 29, 1924, but could not be sampled reliably with the nets in use at the time.

Evaluation of species. In table XIX are listed species comprising more than one per cent of the population in one or more neritic areas in August 1932. The distribution of open gulf forms in inland waters during the warm season is reasonably well indicated, but in the absence of seasonal data from most of the bays it is not possible to determine with any degree of certainty regional variation of neritic zooplankton species having resting stages, invertebrate larvae, or fish eggs and fry, because of possible differences in the periods of augmentation.

In regard to the genus *Acartia,* the three species *A. clausi, A. bifilosa,* and *A. longiremis* no doubt occur to some extent throughout the region but there appear to be some differences in their centres of abundance. The numbers of *A. clausi* in Passamaquoddy bay both in 1931 and 1932, as well as in Maces bay, St. Mary bay and Annapolis basin, show it to be a very important member of the neritic population in the Fundy region. In August, 1932, it was not taken west of Machias bay, or in Frenchmans bay in 1929, although in 1930 it occurred sporadically in the latter area during July and August. From Mount Desert westward *A. clausi* tends to be replaced by *A. bifilosa.* Having its maximum in July this species was not found anywhere in mid-August 1932, but in July 1929 it formed up to 79 per cent in Frenchmans bay and 69 per cent in Blue Hill bay. Again in July 1930 values as high as 64.8 per cent were obtained in the former locality. *A. longiremis* has a more extensive season and is generally more widespread in the open gulf than the other two members of the genus, but in inland waters its centre of abundance in summer appears to coincide with that of *A. bifilosa,* with a possible maximum in early August. In 1932 it was taken in small numbers westward from Machias bay and in 1930 formed up to 41.3 per cent of the population at several stations in Mount Desert waters on August 12.

In addition to those listed in table XIX the following species were taken in small numbers in August 1932:

Boreal species

Anomalocera patersoni (central and Nova Scotian areas)
Clione limacina (all areas)
Euthemisto compressa (central and Nova Scotian areas)
Halithalestris croni (New Brunswick area)
Oithona plumifera (western and central areas)
Oithona similis (western and central areas)
Pleurobrachia pileus (western area)
Stephanomia cara (western and New Brunswick areas)
Tomopteris catharina (western and central areas)

Northern immigrants

Calanus hyperboreus (central area)
Metridia longa (New Brunswick area)

Neritic species

Thalestris longimana (central area)
Melicertum campanula (western area)
Sarsia sp. (central area)

PASSAMAQUODDY BAY

Special attention was accorded Passamaquoddy bay because of its part in the problem confronting the commission (p. 190). Continuous observations, however, could not be obtained because of the other areas included in the program, but it is believed that the available data indicate reasonably well the size and character of the zooplankton population.

VOLUME OF PLANKTON

We have already commented on midsummer volumes in Passamaquoddy bay, which, in common with those of other bays in the barren eastern coastal region, were relatively small compared with inland waters west of Mount Desert (fig. 40) and adjoining waters outside of the headlands (p. 286). Figure 42 shows the latter condition to have persisted at other seasons, the volumes being generally scantier than at station 5 which was itself usually relatively barren compared with station 6 off Grand Manan and station 8A in the path of the entering drift from the gulf.

A combination of environmental conditions apparently accounts for the small volumes characterizing Passamaquoddy bay. Added to the fact that this bay opens into a relatively barren coastal area, during the late autumn and winter months when the local environment would seem to be most favourable for offshore species, the available source of supply in outer waters is approaching a minimum. Later, judging from conditions in the early summer of 1932, the water warms and the winter (offshore) stock declines in Passamaquoddy bay before the influence of vernal augmentation becomes appreciable. Volumes in May, June, and July were smaller than in December and January (table XX). Maximum volumes,

representing propagation by the endemic neritic stock, were found in August and September (1931) at a time when the offshore population in the bay of Fundy had declined greatly from its June maximum (fig. 18).

Typical of neritic localities there appear to be marked variations in the endemic population of Passamaquoddy bay from year to year. In 1931 the dominant summer species, *Acartia clausi,* formed between 50 and 95 per cent of a population averaging 132 cc. in August and 150 cc. in September. In 1932 volumes amounted to only 4 cc. in July, 20 cc. in August, and 36 cc. in September with *A. clausi* never exceeding 33.1 per cent of the stock.

An indication of the interval of time required for local response to quantitative changes in outside waters is seen in the autumnal maximum of *Centropages typicus.* This maximum was reflected in Passamaquoddy bay, but on a very much reduced scale. In 1931 with volumes of 632 cc. in September and 274 cc. in October in the outer Quoddy region (sta. 5), values within the bay amounted to

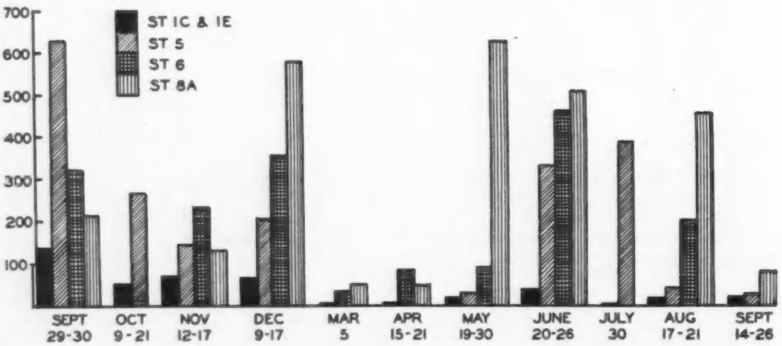


FIGURE 42. Comparative volumes (displacement) in Passamaquoddy bay and the bay of Fundy in 1931-1932. Monthly averages; 20 minute metre net hauls.

only 150 cc. in September and 57 cc. in October (fig. 42). Had the large stock remained in the outer region it is probable that the volume in the bay would have continued to increase, but the interchange appears to be so gradual that the supply in the former locality was depleted before any degree of equalization could be attained. Hence it would appear that, unless conditions following quantitative changes in the fauna of outer Quoddy waters remain fairly constant for some time, only a very limited response can be expected in the inner bay. This matter will be referred to again in considering the passages.

COMPOSITION OF THE POPULATION

Like other inland waters of the region, the zooplankton population in Passamaquoddy bay is composed of the same ecological groups found in the open gulf and bay of Fundy, but the seasonal variations in the relative size of these groups are more extreme. Again the typically coastal groups, comprising neritic plankton

species and larvae of benthonic invertebrates, at times assume far greater importance than in offshore waters.

The open gulf group is always present and for a greater part of the year dominates. The extent to which Passamaquoddy bay is populated by these recruits from outside waters is indicated by the mean of 68.8 per cent for the year 1931-32 and monthly averages ranging from 60.4 to 98.5 per cent between October and the end of June (table XX). Only in the spring (April-May) and late summer (July-October) does there appear to be sufficient local propagation (neritic zooplankton and larvae of benthonic forms) to constitute an appreciable part of the stock.

Northern migrants probably occur more frequently in Passamaquoddy bay than in neritic waters farther west in the gulf. As the two most common members of this group, *Calanus hyperboreus* and *Metridia longa,* are present in small numbers throughout a greater part of the year (p. 247) in the bay of Fundy, occasional specimens may be expected to enter Passamaquoddy bay at any time, but more particularly during the winter months. McMurrich observed *C. hyperboreus* but

Table XX. Composition of the zooplankton population in Passamaquoddy bay. Monthly averages; metre net collections

Year	1931-1932											1917					
Month	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	May	June	July	Aug.	Sept.	Mar.	Apr.	May	Oct.	Nov.	Dec.
No. of hauls	2	2	4	8	4	2	1	1	1	1	1	1	2	2	2	2	1
Volume (settling) cc.	132	150	57	56	61	63	25	47	4	20	36						
Open gulf species	7.9	3.3	60.4	97.9	97.7	98.5	66.5	91.8	49.1	27.0	29.9	87.0	8.6	.3	31.1	55.7	100.0
Northern migrants	T	T	T	T	.6		8.4			T				.1		T	
Southern migrants				T	T												
Neritic species	61.1	95.9	38.2	1.3		1.5	11.6	8.3	43.5	68.2	69.9	10.0	2.5	.9	67.0	35.6	
Fish eggs and larvae	1.6	.1	T	.2	1.8	T	1.7	T	2.8	1.0	T						
Larvae of benthonic forms	21.5	T	1.4	T	T		11.7	T	4.6	3.6	T	3.0	89.0	98.2	.7	T	
Benthonic invertebrates	7.9	T	T	.2					T						1.3	8.6	

once in winter plankton collections of 1914-15 (Willey 1921). In was comparatively numerous on February 23, 1917, sparse (1 specimen) on November 2, 1916, and on March 25, 1920 (2 specimens). Traces were found in each month from August to November in 1931 but none appeared in 1932. *M. longa* was reported by Willey (1921) on December 8, 1916, (1 female) and February. 23, 1917 (scattering males and females). In *Prince* collections from the latter year it was also present in May and November. In 1931-32 it appeared sporadically at all seasons, reaching a peak of 8.4 per cent in May (table XXI).

Only those southern forms which survive for some time in boreal waters would be expected to enter Passamaquoddy bay. With so gradual a rate of interchange through the Quoddy passages (pp. 294 and 301) all but the most resistant species probably perish before reaching the inner bay. No previous records of southern species were found, and none were taken during the summer months of 1931 and 1932. However a single specimen of *Candacia armata* appeared in November and a single *Sagitta serratodentata* in December of the former year. Both are relatively hardy species occurring well into the winter in outer Fundy waters (p. 251).

Neritic zooplankton species comprise the second most important group in Pas-

samaquoddy bay, with a yearly mean of 27.2 per cent in 1931-32. Small numbers have been reported over a wide period, but they are predominately summer and autumn forms with relatively short seasonal maxima in the region. In 1931 they formed 61.1 per cent in August, 95.9 per cent in September and 38.2 per cent in October. They were relatively less numerous in 1932, amounting to 43.5 per cent

TABLE XXI. Evaluation of species in metre net

Year	1931-1932						
Month	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	May
Calanus finmarchicus	5.4	.5	9.5	22.3	35.4	27.0	30.0
Pseudocalanus minutus	1.6	1.8	3.1	6.5	39.5	51.4	28.4
Acartia clausi	51.7	94.2	12.9	1.2			T
Centropages typicus		.2	44.8	49.1	13.8	9.0	
Tortanus discaudatus	7.8	.3	25.3	T			6.6
Eurytemora herdmani	1.6	.6					
Pleurobrachia pileus			T	17.2	3.0	6.6	
Balanus balanoides							8.4
Euphausiid egg		T					3.3
Crago septemspinosus	15.8	T	.8				
Metridia longa		T	T		.6		8.4
Metridia lucens		T		1.4	2.5	3.7	
Acartia longiremis				.06		1.5	5.0
Sagitta elegans	.5	T	.01	.2	.4	T	
Evadne nordmanni		.3					
Podon leuckarti		T					
Podon polyphemoides		.6					
Thysanoessa young							5.0
Temora longicornis	.4	.8	3.0	.2	T	T	
Tomopteris catherina		T		T	1.4	T	
Stephanomia cara			T	.2	.9	T	T
Clione limacina				.3	.8	.8	
Meganyctiphanes norvegica		T	T		T	T	
Fritillaria borealis				.5	T	T	
Obelia sp.					T		
Cucumaria frondosa larva							3.3
Eupagurus sp. larva	2.6						T
Macruran C. larva	2.6	T					
Macruran B larva							
Macruran A larva	.5	T		T	T		
Cancer sp. zoea	T	T	T	T			
Hyas coarctatus zoea							
Enchelyopus cimbrius egg	1.6	.1					
Gadus-Glyptocephalus egg		T	T	.2	1.8	T	
Gadus-Melanogrammus egg							1.7
Urophycis chuss egg							T
Calliopius laevisculus	7.4	T	T	T			
Neomysis americana		T	T				
Autolytus longisetosis	T	T	T	.2	T		
Littorina litorea		T	.6	T			
Aglantha digitalis				T	T		T
Limacina retroversa							
Euchaeta norvegica		T	T	T			
Euthemisto compressa			T	T	T	T	
Halithalestris croni		T	T	T	T	T	
Calanus hyperboreas	T	T	T	T			

in July, 68.2 per cent in August and 69.9 per cent in September. In 1917 values of 67 per cent were obtained in October and 35.6 per cent in November, but as in 1931 (table XX) the group had practically disappeared by December.

Three species, *Acartia clausi, Tortanus discaudatus,* and *Eurytemora herdmani,* comprise the bulk of the neritic stock. The dominant species, *A. clausi,*

appears to have two generations each year, the maximum of adults occurring with the maturing of the second brood in August and September. The presence of copepodite stages (2, 303 per minute) on June 20, would appear indicative of a first generation and nauplii (79,413 per cubic metre) on July 30, of a second (table XXII). *T. discaudatus*, second in importance, may also have two, although

collections in Passamaquoddy bay. Relative percentages

				1917					
June	July	Aug.	Sept.	Mar.	Apr.	May	Oct.	Nov.	Dec.
7.1	2.8	3.7		82.0	7.2	.1	23.7	52.9	93.4
84.7	2.8	9.5	12.1	1.0	1.3	.2	4.2	1.6	
4.2		33.1	17.1		1.5	.4			
	T	5.1	15.7						
1.5	39.4	22.8	6.4	6.0	.7	.5	66.8	35.1	
1.3	.9	5.3	46.4		.3	T			
				3.0	89.0	98.2			
	42.6	1.7	.7						
	3.2								
		T				.1		T	
T	T	.2							
				4.0				.5	
T	T	T		3.0	T	T	.9	..7	6.7
	.9	3.6							
.8	T	2.2	T						
			T						
		2.9	1.4	1.0	.1		1.5	.5	
		T							
	.9								
		T							
	T	1.5							
		2.2							
.5		1.2	T						
T		.2	T						
		.5			T		.7		
		1.9	T						
	1.4	.5	T						
T	T	.5						T	
	2.3								
		T							
T	.5								
T		1.0	T						
	T								
	T							4.8	
			T				1.3		
		.2	T						
T						T			
						T			

this has not been definitely established. In 1932 it formed 39.4 in July and declined to 6.4 per cent in August. Later adults rose from 0.3 in September to 25.3 per cent in October 1931, and to 66.8 in October and 35.1 per cent in November, 1917. This would suggest two generations with a developmental period of approximately two months as in *Calanus, Pseudocalanus,* and *Oithona similis*

(Fish 1936a, 1936b and c). However, as the total volume of zooplankton diminished with the decline of *Acartia,* the fluctuations in the case of *Tortanus* may only be apparent and result from a somewhat longer period of adult life.

E. herdmani, which was found swarming on occasions in bays of the gulf (p 292), never assumed that importance in Passamaquoddy bay during the period of the present observations. For the most part it occurred in small numbers, but in September 1932 reached 46.4 per cent. During the previous year it averaged 1.6 per cent in August, 0.6 per cent in September and thereafter appeared to have been absent until the following June.

Larvae of benthonic invertebrates are of spring and summer occurrence, reaching peaks in April-May (98.2% in 1917) and August (21.5% in 1931). With the breeding season in most species extending over a relatively long period (p. 270), concentrations of large size are rarely found. An exception occurs in the case of *Balanus balanoides,* whose breeding period varies greatly in different localities (p. 271), but in any one area is relatively restricted. Nauplii in Passamaquoddy bay appear in March and swarm in April and May. No very high percentages were found in 1932, the greatest being 8.4 per cent in May, but in 1917 they ranged from 3 in March to 89 in April and 98.2 per cent in May. A second species, *Crago septemspinosus,* appeared from July to October and reached a peak of 15.8 per cent in August, but no other larvae of this group exceeded 3 per cent at any time.

There was no evidence that adult benthonic invertebrates are ever of significance in the zooplankton association in Passamaquoddy bay. Nets coming in contact with the bottom invariably encountered a variety of Cumacea, amphipods, isopods, mysids and other forms existing on or adjacent to the bottom, but such hauls were discarded and only species pelagic at the time of capture recorded. For the most part these occurred as single specimens probably accidentally transported upward by turbulence or attached to some floating object. The sexual stage of *Autolytus longisetosus,* however, was definitely free-swimming at the time of capture and occurred in small numbers from August to December in 1932. In October 1917 it formed 1.3 per cent of the haul. *Calliopius laeviusculus* and *Neomysis americana* were also found in small pelagic swarms. Both of these species are regularly found at the surface during the breeding season in other localities (Fish 1925). There are a few other benthonic forms in the region which are known to be pelagic at times, but did not occur in the present collections. It would thus appear that normal turbulence is not sufficient to maintain benthonic species in the upper levels in Passamaquoddy bay, and those torn from the bottom during storms quickly settle after the water subsides.

Pelagic fish eggs and larvae, as in outer waters, differ from the young of invertebrates in the region in that they occur to some extent throughout the year. They were present in very small numbers in Passamaquoddy bay, however, having a mean value of but 0.8 per cent in the zooplankton population for the year 1931-32. The highest monthly values occurred in July (2.8%) and August (1.0%)

in 1932, and August (1.6%) and December (1.8%) in 1931 (table XX). Approximately ten species are represented in the collections of the two years.

Evaluation of species. Eight species at all times (with one exception, 68.1% in August, 1931) in 1931-32 and 1917 were found to comprise more than 75 per cent of the population (table XXI). Of these, four (*Calanus finmarchicus, Pseudocalanus minutus, Centropages typicus,* and euphausiid eggs) represent boreal offshore species, three (*Acartia clausi, Tortanus discaudatus,* and *Eurytemora herdmani*) are neritic, and one (*Balanus balanoides*) is the larva of a benthonic invertebrate.

Fifty-nine other species were taken during the period of the observations but were rarely found numerous. Only a few at any time exceeded 5 per cent. Of these *Pleurobrachia pileus* formed 17.2 in November and 6.6 per cent in January. *Sagitta elegans,* another boreal species, amounted to 6.7 per cent in December 1917. A local swarm of the northern migrant, *Metridia longa* entered the bay in May 1932 and for a short time ranged up to 8.4 per cent in the small population present at the time. On another occasion the amphiphod *Calliopius laeviusculus* formed 7.4 per cent of a haul in August 1931. Occasional swarms of other neritic and benthonic species may be expected at times but these are probably sporadic and of short duration.

The following additional species occurred in very small numbers in Passamaquoddy bay (1931-32 unless otherwise noted).

Aeginella longicornis, Sept.
Ammodytes americanus, May
Anomalocera patersoni, Sept., Aug.
Candacia armata, Nov.
Centropages hamatus, Oct. (1917)
Clupea harengus larva, Oct.
Corophium cylindricum, Sept.
Cyclopterus lumpus, young, Sept.
Diastylis sculpta, Aug.
Enchelyopus cimbrius, larva, Oct., June, July
Erythrops erythropthalma, Nov. (1917)
Glyptocephalus cynoglossus, larva, Oct.
Hippoglossoides platessoides, egg, May
Hybocodon prolifer, April, May (1917)
Lumpenus lampetraeformis, young, July
Melanogrammus aeglifinus, young, July
Oikopleura labradoriensis, Dec., Oct. (1917)
Oithona plumifera, Oct., Dec., Jan.
Phialidium languidum, Oct., July
Sagitta serratodentata, Dec.
Thysanoessa inermis, Sept., Nov., Dec.

Because seasonal variations in the composition of the population in Passamaquoddy bay are of far greater magnitude than in offshore waters, the annual cycle must be considered in evaluating species. It will be seen in table XXI that the population consists in general of a winter group (November until April) derived from outside waters, but with *Pseudocalanus* assuming somewhat greater relative importance in Passamaquoddy bay; a spring augmentation of *Balanus balanoides* larvae from March until May; a gradual replacement by neritic species in late June and July (table XXII); and an autumnal invasion of *Centropages typicus* in

September which dominates until the winter stock is again recruited from the bay of Fundy with the cooling of the waters.

Considering local propagation in Passamaquoddy bay, with the possible exception of *Pleurobrachia pileus,* which appears in very early stages in late October and grows rapidly until it often forms the bulk of the collections, no winter propagation of invertebrates was observed, and the remainder of the boreal stock is believed to consist of immigrants (Fish 1936a, 1936b and c).

The benthonic invertebrate stock is no doubt to a large extent of local origin, although late stages of some of the decapods such as *Cancer* and *Hyas* were rarely taken.

The neritic stock is also probably largely endemic with one or at most two broods a year. In the case of the greater number of species, including the higher crustaceans, there is not more than one. Some of the neritic copepods, as previously mentioned (p. 298), show evidence of two, the larvae, probably developing from winter eggs, appearing some time before the adults (table XXII). Thus *Temora*

TABLE XXII. Decline of the winter population and rise of the endemic neritic community in the summer of 1932. Station 1C (Passamaquoddy bay)

1932	May 30	June 20	July 30	Aug. 21	Sept. 23
Type of haul. Net	Metre	Metre	Metre	Metre	Metre
Depth	35-0	35-0	35-0	30-0	34-0
Volume (displacement) 20 min.	8.0	26.7	1.9	12.0	13.3
Relative percentage	*	*	*	*	*
Calanus finmarchicus	30.0	7.1	2.8	3.7	
Pseudocalanus minutus	28.4	84.7	2.8	9.5	12.1
Metridia longa	8.4				
Balanus balanoides larva	8.4				
Tortanus discaudatus	6.6	1.5	39.4	22.8	6.4
Euphausiid egg	3.3		42.6	1.7	.7
Acartia clausi	?	4.2		33.1	17.1
Eurytemora herdmani		1.3	0.9	5.3	46.4
Centropages typicus			?	5.1	15.7
Temora longicornis				2.9	1.4

1932	June 20	July 30
Type of haul	½ metre Net	Pump
Depth	30-0	30-0
Number per minute	*	
Number per cubic metre		*
Calanus finmarchicus egg		
Calanus finmarchicus nauplius		160
Calanus finmarchicus copepodite	?	80
Pseudocalanus minutus egg	2,847	760
Pseudocalanus minutus nauplius	4,745	1,067
Pseudocalanus minutus copepodite		147
Temora longicornis nauplius	2,373	21,693
Temora longicornis copepodite		
Acartia clausi nauplius		79,413
Acartia clausi copepodite	2,303	1,987

longicornis nauplii formed 2,373 per minute in net hauls on June 20, and 21,693 per cubic metre in pump samples on July 30, although no adults were taken until mid-August of that year. Traces of *Acartia clausi* in late copepodite stages in late May several weeks before the adults were first observed (June 20) in 1932 affords another example.

The present data are not sufficient to indicate the extent of vertebrate propagation in Passamaquoddy bay, as both eggs and larvae usually appeared in very small numbers (table XXI). Battle's (1930) work in this area would suggest that, as in the bay of Fundy (Huntsman 1918, 1922), propagation by species with pelagic eggs is largely unsuccessful.

ZOOPLANKTON INTERCHANGE WITH THE OUTER QUODDY REGION

The extent of zooplankton interchange between Passamaquoddy bay and the Outer Quoddy region through the three passages (fig. 41) must necessarily be proportional to the amount of water replacement, and hydrographic results indicate that such replacement is very slow (Watson 1936). Apparently the nature of the mixing mechanism is such that water tends to be drawn into the passage at the surface and bottom and retraces its steps at a mid-depth after mixing. This

takes place at the two ends of the passage. The maximum volume of mixed water occupies the greater part of the passage and is slowly replaced. Furthermore, according to Watson (1936, p. 183), "It appears that a large fraction of the water which comes out of the passages on the ebb tide returns into them on the succeeding flood and that the residual outflow of mixed water over a complete tidal interval is quite small."

According with this hydrographic evidence, biological observations, which were inaugurated during the peak of neritic propagation in mid-summer (1931), indicated from the beginning the existence of some barrier obstructing, to a considerable degree, the passage of zooplankton to and from Passamaquoddy bay. The endemic Passamaquoddy population was found to be restricted largely to the bay and the inner part of the Western passage (table XXIII). Elsewhere even at the end of the ebb tide the population in the passage consisted almost entirely of an immigrant stock from the bay of Fundy. Herring stomach analyses also indicated neritic species to be the principal food in Passamaquoddy bay, and offshore species the sole food in specimens from the passage (Johnson 1934, Battle, Huntsman et al. 1936, p. 419).

Repeated observations in 1932 (table XXIV) yielded substantially the same results except that at times neritic forms in relatively small numbers were found more widespread in the Western passage, and somewhat more abundant throughout the two Letite passages. In the latter area, however, there was a marked decline in the passages upon leaving the bay, and little evidence of dispersal beyond the immediate vicinity of the outer entrances.

As most of the fresh water entering Passamaquoddy bay passes out through the Western passage (Watson 1936, p. 195), replacement must be most active there. In the following table showing a comparison of the population in Passamaquoddy bay, the inner part of the Western passage and the outer part, observations in 1931 have been selected because in that year the neritic stock was much larger than in 1932, and with the dominant endemic species, *Acartia clausi,* ranging from 95.0 to 98.1 per cent, the extent of dispersal into the passage should be well indicated. These two bay stations being rather shallow, metre net hauls were made only at the surface. Near the bottom in deeper parts of the bay the relative percentage of *A. clausi* was probably somewhat smaller.

It will be seen that in the outer part of the passage (fig. 40, sta. 4) after the tide had ebbed for two and one-half to three hours *A. clausi* was totally absent, the hauls both at the surface and lower levels consisting almost entirely of boreal offshore species and larval benthos. In the inner part of the passage approaching Passamaquoddy bay (sta. 2) neritic species appeared in greater abundance at the surface, but the highest values occurred near the end of the flood tide and not when the water in the upper layer would have been expected to be entering from the bay on the ebb. Even at this inner station the boreal stock amounted to more than 80 per cent in the subsurface zone on both phases of the tide.

It would therefore appear that the relatively slow replacement of water in the passages (Watson 1936, p. 183) forms an effective barrier to rapid transit of

plankton organisms and the contributions from Passamaquoddy bay must be negligible even in the Outer Quoddy region. It is possible that during the spring freshets interchange is much more rapid, but these probably result in no detectable difference in the character of the zooplankton, because they occur before there is appreciable local propagation of either neritic or boreal species, and at a time when immigrant juveniles of the gulf stock in the upper levels tend to keep out of the Quoddy region in circuiting the bay of Fundy (Watson 1936, p. 188).

Referring again to tables XXIII and XXIV it is seen that in the Western passage even the smaller zooplankton organisms show a distinct stratification in

TABLE XXIII. Composition of the zooplankton population at selected stations in the Western passage and Passamaquoddy bay on different phases of the tide. Relative percentages in metre net collections.

Location	Passamaquoddy Bay		Western Passage (inner part)				Western Passage (outer part)			
Station	1E	1B	Cummings Cove to Kendall's Head (st. 2)				Off Wilson Head (st. 4)			
Date, 1931	Aug. 13	Sept. 14	August 8				September 16			
Phase of Tide (hours)	5E	2½E	5E	4½E	5½F	5F	3E	2½E	4½F	4½F
Depth of haul (metres)	0	0	0	33–44	0	37–40	0	25–35	0	25–30
Volume (settling) in cc. (20 min)	256		26	29.5	14.5	14	156	87	356	320
Acartia clausi	96.1	95.0	22.6	T	78.2	.8				.4
Calanus finmarchicus	T			91.2	* 1.2	69.0	53.1	31.8	34.9	42.5
Calanus hyperboreus			.9	.4			T	T	T	T
Centropages typicus		T			2.3		7.9	15.5	4.2	7.1
Euchaeta norvegica				T		1.6				T
Eurytemora herdmani		.4	T		2.4					
Halithalestris croni							1.0	7.5	.5	
Metridia longa				1.3		1.6		T	T	T
Metridia lucens						7.2		3.5	1.0	5.3
Pseudocalanus minutus		T	.4		4.1	.8	17.4	34.1	8.4	17.3
Temora longicornis	.7	T	.8		1.2					T
Tortanus discaudatus	.7		T	.4	T	T		.3	.5	.4
Balanus crenatus larvae			.4		.6					
Evadne nordmanni		1.4			T					
Podon leuckarti		T	T		.6					T
Podon polyphemoides		2.1	T		T					
Diastylis sculpta	T			.4		.8				
Calliopius laeviusculus		T							.5	
Euthemisto compressa								T	.5	
Meganyctiphanes eggs			17.8	.9	7.6	.8	17.3	13.4	40.5	20.3
Meganyctiphanes larvae		T	.4		T			.3		T
Thysanoessa inermis								T	T	
Thysanoessa neglecta								T	T	
Crago septemspinosus larvae	.7	T		.4	T	4.8		T		T
Cancer sp. zoea	T		T	T	T	8.0	T	T	.5	.4
Hyas coarctatus zoea										.4
Phialidium languidum							1.0	1.7	2.8	2.2
Turris vesicaria										T
Stephanomia cara							1.0		5.6	2.6
Aurelia aurita eggs			36.1							
Aurelia aurita larvae			13.5							
Sagitta elegans				1.3		.8	T	.6	.5	.9
Sagitta maxima							T	T		
Autolytus longisetosis			T	T	T		T	T	T	T
Tomopteris catharina							T	T	T	
Clione limacina larvae			T		T			T		
Littorina litorea eggs				.8	T	1.6				
Mytilus edulis larvae			5.2	1.7	T	T				T
Enchelyopus cimbrius eggs		.7	1.7	1.3	1.2	1.6	.5	T		
Tautogolabrus adspersus eggs							T			

daylight collections though the water was rather well mixed at the time. In table XXIII, the neritic species *Acartia* formed 22.6 per cent at the surface and but a trace between 33 and 44 metres on August 8, 1931, at station 2 (ebb tide), while *Calanus,* absent entirely at the surface, amounted to 91.2 per cent at the latter level. Similar stratification is seen in the vertical range of *Centropages* at this station in 1932 (table XXIV). Vertical differences in concentration are not so easily demonstrable at station 4 off Wilson head in the outer part of the passage, because the zooplankton population consisted for the most part of but one ecological group. However in table XXIV it is seen that *Centropages* formed

81.4 per cent in an oblique haul of 109 cc. and only 35.2 per cent in a haul of 31 cc. taken simultaneously at the surface. Again, although the species are not given, definite stratification is indicated in the outer passage (Calder beach) in a haul made on the flood tide on July 27, 1933, (Battle, Huntsman, et al. 1936, table X). At this time large copepods were almost three times as abundant and small copepods five times as abundant at the surface as at five metres.

Stratification of planktonic animals in a homogeneous water mass would appear to be most readily explainable in the following manner: considering that the uniform distribution of temperature and salinity in such a mass must result from gradual eddy diffusion, animals without power of motion would also be expected to gradually become evenly distributed throughout the mass in a similar manner. Although transported in various directions their average displacement would probably be so small that with any power of independent locomotion, however feeble, they might easily counteract this diffusion process and respond to the same factors controlling their movement in more stable areas. To maintain themselves at any favourable level it would only be necessary to travel vertically at a rate greater than the rate of vertical eddy diffusion. Zooplankton organisms in the region are capable of a diurnal migration frequently exceeding 50 metres and sometimes 100 metres (Clarke 1934a, p. 538; 1934b, p. 447), whereas, although actual figures are lacking, the vertical rate of diffusion in the sea can hardly amount to 50 metres in 12 hours.

TABLE XXIV. Composition of the zooplankton population at selected stations in the Western passage. Relative percentages in metre net collections

Western passage	Inner part (station 2)				Outer part (station 4)		
1932	Sept. 12		Sept. 13		Sept. 13		
Phase of tide (hrs.)	5¼E	5¼E	5½F	5½F	Low water	4½F	4½F
Depth of haul (metres)	0	30-0	0	39-0	30-0	0	39-0
Volume (displacement) cc.	7	11	10	31	17	31	109
Calanus finmarchicus		T		6.8	2.1	5.2	13.8
Centropages typicus	6.6	82.5	31.2	77.7	78.4	35.2	81.4
Acartia clausi	77.6	10.1	45.8	7.4	3.6	1.8	T
Eurytemora herdmani	3.7		3.6	1.9	1.1	0.3	
Temora longicornis	3.3	0.3	0.4	0.4			
Tortanus discaudatus	0.4		T	1.5	0.8		
Evadne nordmanni	1.2		1.1				

The foregoing comments refer to a homogeneous water mass. As a matter of fact the water in the Western passage, although mixed, was usually found to be

not entirely homogeneous. Vertical temperature gradients up to and even exceeding 3°C. in 40 metres were found at times, particularly on the ebb tide. (On August 8, 1931, at the time of the ebb tide hauls listed in table XXIII, the following temperature and salinity values were obtained: Surface, 14.1°C., 30.66‰; 10 metres, 11.11°C., 31.49‰; 25 metres, 10.41°C., 31.53‰; 40 metres, 10.84°C., 31.55‰). Supplementing these repeated records of slight temperature and salinity gradients, the observed vertical stratification of euphausiid eggs (without power of locomotion) in violently turbulent water would appear indicative of rather limited vertical displacement as compared with lateral eddy movement. Animals could hardly be transported passively to the surface by mechanical mixing in water exhibiting even slight thermal stratification. Violent vertical mixing may take place in whirlpools on certain phases of the tide, and at such times animals may be distributed through the mass, but these are local phenomena and the zooplankton appears to quickly stratify out again. Eggs of *Meganyctiphanes norvegica* at station 4 on September 16 (table XXIII) were twice as abundant in a haul of 356 cc. at the surface as in a haul of approximately similar volume (320 cc.) at 25-30 metres. The percentage difference was also great between the surface and lower levels at station 2 on August 8 both during the flood and ebb tide, as seen in the same table. Similar vertical differences were also observed at station 2 on September 16 (15% at surface, 4.6% at 36-40 metres) and station 4 on September 15, 1931.

In light of the foregoing observations there would seem to be little doubt that the swarms of actively swimming euphausiids, commonly observed during the summer at the surface in the Western Quoddy passage and less frequently in other turbulent areas like Frenchmans bay (Dahlgren 1925) and the outer part of the bay of Fundy (S. I. Smith 1879, p. 90; Moore 1898, p. 401), are not passively transported from the lower levels. On one occasion while a hydrographic station was being made between Eastport and Welchpool (station B. W., fig. 21, Watson 1936) on August 7 some of the largest local swarms observed in 1932 appeared at the surface with the water stratified to the extent indicated in the following table:

Depth (metres)	Density	Salinity (‰)	Temperature (°C.)
0	24.65	32.09	10.30
5	24.72	32.09	9.88
10	24.79	32.12	9.65
20	24.82	32.16	9.60

Why then do euphausiids appear at the surface by day in this locality? With so little positive evidence it is dangerous to hazard a guess. The abundance of eggs (table XIX, sta. M1 and M5) indicates that *Meganyctiphanes norvegica,* the species most commonly reported, is generally distributed along the New Brunswick coast in summer and might be expected to enter the passage at any time. That the concentrations observed at the surface represent sporadic invasions of short duration and not a resident population is suggested by the fact that in both

1931 and 1932 attempts to obtain material one or two days after swarms had been reported repeatedly proved unsuccessful. On such occasions none were found at the surface and at best only occasional specimens in the lower levels. Again the fact that our surface collections of *Meganyctiphanes* concentrations have consisted entirely of large mature adults, although juveniles of 12 to 18 mm. dominated the population in the region at the time (p. 313), would also suggest a swarm of one size group. This might be considered indicative of a spawning migration were it not that at times the swarms in late summer were found to contain a considerable number of *Thysanoessa* which terminates its spawning season everywhere in the region before the end of June. In one such collection taken by Dr. A. H. Leim at the surface in the Western passage on August 31, 1933, three species of *Thysanoessa* outnumbered *Meganyctiphanes* 295 to 35. Yet all records at hand occur in the period between March and September (Bigelow 1926, p. 150), which coincides with the spring and summer spawning period of the latter species. Thus on the basis of this apparent short sojourn of individual concentrations (although invasions may be of frequent occurrence particularly in August and September) of one age group (individuals 28-31 mm. exceeding 87% in the case of *Meganyctiphanes*), it may be suggested that migrant swarms entering the passage find the turbulent water unfavourable and, disregarding their usual day levels, swim about actively in an effort to escape to the more stable conditions to which they are accustomed. Were euphausiids present continuously in such numbers in the passage during the summer months, they should appear more regularly in net hauls than the records indicate (table XXIII).

DISCUSSION

In the foregoing chapters an attempt has been made to analyze the composition of the zooplankton population in the region, quantitative and qualitative seasonal changes, and those physical environmental conditions considered to have the most readily detectable influence on its production and geographical distribution.

Composition of the Population

The dominance of Crustacea in the animal plankton is clearly indicated in all available data from the gulf and bay of Fundy. As shown in the following table (XXV), even during the period of greatest propagation of other invertebrates, from April to September in 1932, crustacean averages for the region ranged from 87.2 to 97.6 per cent. Copepods usually comprise the bulk of the stock (numerically) except in some localities in the immediate vicinity of the coast during the barnacle breeding season (April-May), and in very limited areas when swarms of other Crustacea (euphausiids, Cladocera, and less commonly amphipods), Sagittae, Medusae, molluscan larvae and rotifers occur. Such swarms are usually of rather short duration and exert little influence on averages for the region as a whole.

Another important characteristic is the remarkable uniformity of the population in the open gulf at all times, consisting largely of boreal endemic species. In inland waters there is the addition of and sometimes to a large extent replace-

ment by neritic forms and larvae of benthonic invertebrates in spring and summer, but their range of appreciable influence rarely extends far offshore. Eggs and larvae of but a few species of vertebrates are found in very large numbers and then only for comparatively short periods, as rapid dispersal from offshore spawning areas quickly dilutes the stock. The two remaining ecological groups represented in the region, northern and southern migrants, are chiefly of interest as indicators of inflow into the gulf.

TABLE XXV. Relative percentages of copepods and other Crustacea

1932	TOTAL AREA			GULF OF MAINE Western area		
Month	% copepods	% other crustacea	total crustacea	% copepods	% other crustacea	total crustacea
April	45.3	41.9	87.2	52.8	35.6	88.4
May	77.2	15.2	92.4	84.0	9.2	93.2
June	85.5	11.7	97.2	82.5	15.4	97.9
Aug.	72.4	18.1	90.5	68.2	22.1	90.3
Sept.	96.9	.7	97.6	99.5	T	99.5

Although some 30 members of the dominant boreal group are common to the region, the population throughout the year is composed largely of a very few species. But six forms, shown in the following table (XXVI), averaged more than one per cent, and these in all observed offshore areas of the gulf and bay of Fundy totalled more than 83 per cent.

TABLE XXVI. Relative percentages of the six dominant boreal endemic forms. Average values within the

	Bay of Fundy				April - September	
	Year	Year	August-Sept.		Western	Central
	1917	1931-32	1931	1932	area	area
Calanus finmarchicus	80.7	38.6	49.1	35.6	45.3	49.1
Centropages typicus	.1	22.6	7.4	26.0	8.2	3.2
Pseudocalanus minutus	8.1	10.0	3.9	4.2	3.9	6.2
Metridia lucens	1.3	7.1	2.3	10.0	19.4	15.6
Euphausiid eggs	2.7	8.9	28.6	8.7	11.6	10.9
Sagitta elegans	2.6	2.2	2.2	1.6	.4	.5
Total %	95.5	89.4	93.5	86.1	88.8	85.5

BIOLOGY OF THE ZOOPLANKTON POPULATION

ANNUAL CYCLE

In so nearly a closed system as the gulf, quantitative fluctuations in the zooplankton are indicative of periods of local augmentation and depletion. The population is at a minimum in late winter and early spring. In the case of such typically boreal copepods as *Calanus, Pseudocalanus, Oithona* and *Microstella*, the winter stock consists of late copepodites which mature and spawn with the warming of the water in early spring. Beginning in March or early April there is a series of three or four generations, each ranging from six weeks to two and one-half months, until September. Thereafter the stock remains in late developmental stages to form the winter population.

In *Centropages typicus,* showing both neritic and open gulf characteristics, there is some indication that there may be a winter egg as the species is sparse or absent for much of the year. Larvae in 1932 appeared as early as June but did not become abundant until August. There is one brood in the eastern gulf and possibly two in that portion of the population originating west of Mount Desert, but this has not been definitely established. The stock reaches its peak in September and declines during the early winter (fig. 43).

in the zooplankton population in 1932. Metre net collections

Central area			BAY OF FUNDY		
% copepods	% other crustacea	total crustacea	% copepods	% other crustacea	total crustacea
28.5	66.7	95.2	54.5	23.5	77.9
74.5	18.9	93.4	73.1	17.4	90.5
85.3	12.2	97.5	88.7	7.4	96.1
83.3	8.9	92.7	65.3	23.4	88.7
100.0	0	100.0	91.2	2.3	93.5

Neritic copepods are summer spawners in this region and for the most part have a winter resting stage. The more common species, *Acartia, Tortanus,* and *Temora* in Passamaquoddy bay, appear to pass through two generations before declining in the autumn.

In the higher Crustacea there is but one annual brood. The most common

calculated from the total zooplankton population in metre net collections from all stations designated areas

1932		May 1932			September 1932		
Offshore gulf	Bay of Fundy	Off Cape Ann	Eastern channel	Brown's bank	Outer gulf	West coast Nova Scotia	Georges bank
49.5	39.3	74.9	91.0	46.6	28.3	62.6	1.8
.2	10.4	1.1			.3	13.7	88.8
1.6	16.0	11.8	1.0	47.2		11.4	.3
30.8	6.9	9.8	4.0		32.6	T	1.8
7.9	7.0	.3			.1		
.2	4.3	T	T	1.6	T	3.1	2.6
90.2	83.9	97.9	96.0	95.4	61.3	90.8	95.3

euphausiids, *Meganyctiphanes* and *Thysanoessa,* like the copepods, pass the winter in late juvenile (cyrtopia) stages and mature with rising spring temperatures.

In most of the non-crustacean species there is also indication of but one generation each year, but one at least, *Sagitta elegans,* has been shown to have several (Russell 1932, p. 141). Our data have not yet been fully analyzed, but the repeated maxima of eggs and different size groups during the summer suggest an annual cycle in the region somewhat comparable to that of boreal copepods. The propagation period would appear to be longer than that of copepods however, since well advanced young (11-15 mm.) were found in the gulf in late April in 1932, and eggs in the bay of Fundy on October 2 in 1917 (Huntsman and Reid 1921, p. 107).

Adults of most planktonic animals apparently die off soon after spawning, the males preceding the females in the case of *Calanus*. This results in a replacement of the stock with each generation. Euphausiids may form an exception, for, although largely replaced each year, a part of the population in the bay of Fundy appears to survive a second year (no evidence was found to indicate that the euphausiid stock in the gulf is not wholly replaced each year). Old adults of 28 to 35 mm. were present in the bay in November 1931 when the largest members of the earliest spring crop (April) had not yet attained a length of 24 mm.

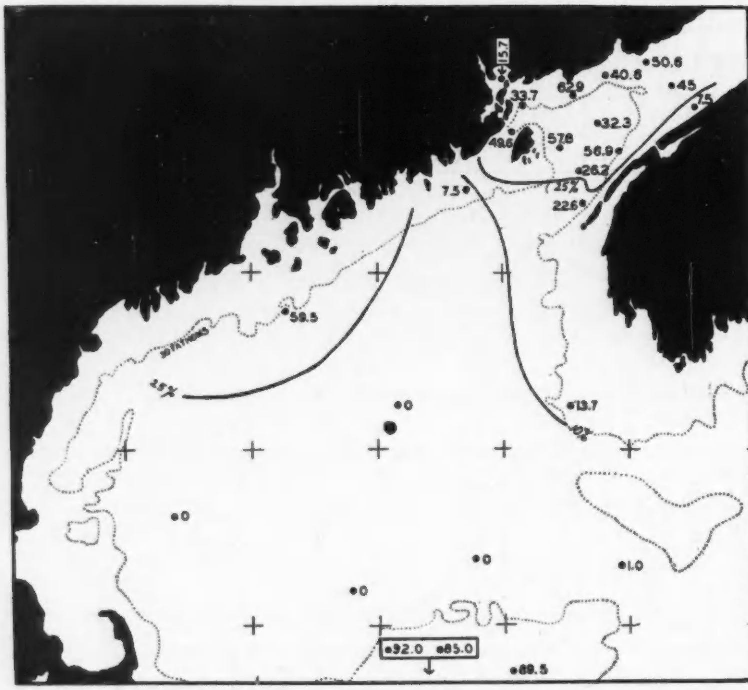


FIGURE 43. Distribution of *Centropages typicus* in September, 1932. Relative percentages in metre net collections.

BREEDING STOCKS

Being closely correlated with temperature, the delay in vernal warming to the eastward in the inner gulf is reflected in the breeding periods. Earliest propagation appears to take place in the outer gulf, followed by the western coastal zone and thence eastward to the bay of Fundy. The New Brunswick side of the bay is the last to respond, due to the influence of the Saint John outwash (Watson 1936, p. 188). There is an average difference of about one month in the time of spawning of observed boreal species in each of these three general areas, beginning

in the outer gulf in early March, the western area in early April and the eastern gulf, including the bay of Fundy, in May or later.

On the basis of this regional variation in the time of spawning, it is possible to distinguish different breeding stocks. "These stocks are not permanently restricted to their respective localities, but merely represent delayed maturation of that portion of the winter population . . . . . . which happens to be located in the eastern part of the gulf and bay of Fundy during the spring, and earlier maturation in areas to the westward where the water mass responds more rapidly to vernal warming" (Fish 1936b, p. 197). However, with the annual cycle starting at significantly different times, and with approximately the same interval of development, the distinct breeding periods are continued in subsequent generations that year, no matter where the young are dispersed, any acceleration of growth in members of the eastern stock transported into the warmer western area being of minor degree.

A possible explanation of the ripening of the gonads of the outer gulf and western breeding stocks almost coincident with or even preceding vernal warming of the upper strata, may be found in the inflow of warm bottom water which maintains uniform temperatures of 5 to 6°C. in the basin of the gulf throughout the winter (p. 195). In areas not so affected, sexual development of even two year old euphausiids is much slower.

PRODUCTION AREAS

The vernal crop (March-April) of boreal species appears to be derived largely from adults maturing in the western or outer gulf. In some, like *Calanus finmarchicus* (Fish 1936a) and *Meganyctiphanes,* where an offshore brood was not detectable, the western coastal area may form the principal source of the population in the region. In others, like *Pseudocalanus* and *Oithona similis,* the bulk of the stock following the first brood appears to be derived from the outer gulf and eastern basin (Fish 1936b and c). A barren spring and abundant summer plankton was also observed by Bigelow (1926 p. 89) in the eastern basin (see p. 223).

Two distinct populations of *Centropages typicus* were found in 1932. One was confined to the inner gulf and bay of Fundy. The other occurred over Georges bank where it formed up to 92 per cent of the zooplankton in mid-September. Although abundant at all stations on the bank, none were taken in the basin of the gulf or in the drift to the coast.

The source of *Metridia lucens* remains problematical, for although ranking fifth (7.1%) in the bay of Fundy zooplankton in 1931-1932, and second (17.5%) in the gulf during the period April-September (1932), eggs and early larvae were entirely absent in all collections. (But three specimens of unidentified nauplii representing two species were taken during the period of the investigation). In its general distribution in the western Atlantic and relative abundance in the gulf, it shows the characteristics of a typical boreal form. However, in Bigelow's records covering a period of years there was no evidence of concentrations indicative of local centres of reproduction and "the fact that it has been found most

regularly in the eastern and southern parts of the gulf points to a certain amount of immigration via the two channels and across Browns bank from the continental shelf off Nova Scotia" (1926, p. 262). His chart of centres of abundance during the year (p. 257) also suggests a winter population in offshore waters, with a movement into the eastern coastal area following vernal augmentation. These records, combined with the fact that appreciable propagation could hardly take place anywhere within the gulf and not be indicated in collections covering the spring and summer period, justify a tentative conclusion that the *Metridia lucens* population consists largely if not entirely of immigrants from outside waters. An important propagation area must be located near the entrance to the gulf, however, because young reach the inner coastal region in fourth and fifth copepodite stages. The following relative percentages of copepodites to adults occurred in the general region in 1932: April 36.7, May 81.4, June 58.4, August 77.8, and September 70.6

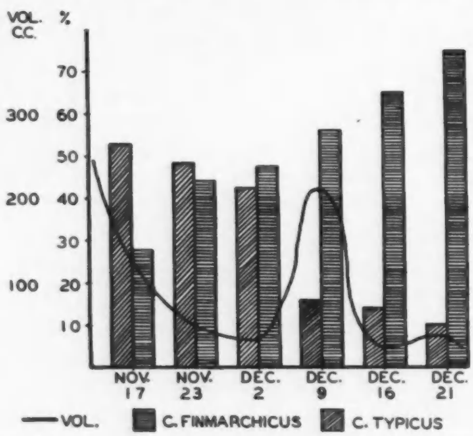


FIGURE 44. Showing decline of *Centropages typicus* stock in 1931.

per cent. The rise in copepodite values in May and August may represent successive broods of migrants. Augmentation by juveniles on these occasions was particularly evident in the Quoddy region (sta. 5). Here on March 5 and April 15 the hauls yielded only adults. An influx of copepodites, amounting to 60 per cent of the *Metridia* stock on the nineteenth, occurred in May. Small numbers of adults only were found on June 20 and July 30, but in August copepodites again appeared and rose to 66 per cent by September 26.

A comparison of the quantitative distribution of adults (figs. 15 and 16) and larvae (Fish 1936a, 1936b and c) of boreal endemic species with summer temperatures (figs. 6 to 9) shows a close correlation. Localities sparse in all stages coincide with the range of minimum surface temperatures. Previous evidence of unsuccessful development at low temperatures has been found in *Enchelyopus cimbrius* in Passamaquoddy bay (Battle 1930), and in *Sagitta elegans* (Huntsman and Reid 1921, p. 110), *Calanus finmarchicus* (Miss N. E. Wright in Cowie 1929)

and fishes having pelagic eggs (Huntsman 1918, p. 65) in the bay of Fundy. Miss Wright's statement that the surviving *Calanus* stock enters the bay of Fundy in copepodite stages agrees with present results, but the basis for her conclusion, i.e. almost complete absence of early stages, seems erroneous. Eggs (up to 19,444 per min.) and nauplii were widespread and often in comparatively large numbers in the bay during the propagation period both in 1931 and 1932 (Fish 1936a).

However, in the western gulf adults of the boreal plankton population occur regularly at night at the surface at temperatures of 19°C. or more, and larvae by day at depths of 25 to 50 metres at temperatures ranging as low as 8°C. (Gran and Braarud 1935, fig. 296). Euphausiid larvae, for example, in cyrtopian stages in August were found in greatest abundance during the daylight hours at temperatures below 8°C. off Casco bay, but not in the bay of Fundy where the surface water averaged from 12 to 14°C. at the time. It is therefore evident that other factors must also be taken into consideration.

Whereas a combination of two factors, light and turbulence, apparently serves to restrict diatom production in the bay of Fundy (Gran and Braarud 1935, p. 280), it has been suggested that turbulence and temperature account for the lack of successful propagation and the small population of boreal zooplankton (Huntsman 1918; Fish 1935) in the coastal zone eastward from Mount Desert (including the bay of Fundy). "The observed descent of larvae to levels of relatively low temperature by day and the rise of adults to warm surface waters at night indicate that all can apparently survive the most extreme conditions existing in the region provided that there can be periodic access to water within the required thermal range." (Fish 1935, p. 98). In turbulent areas like the bay of Fundy and eastern coastal portion of the gulf where throughout the summer one finds neither warm surface nor cold bottom water, environmental conditions would not appear to be favourable either for adults or young.

The influence of these two factors is also seen in the records from inland waters. In Frenchmans bay in 1930, with low bottom (6.9 to 10°C.) and surface (12 to 15°C.) temperatures (July-September), the latter resulting from moderate tidal mixing in the upper levels, a comparatively abundant stock of boreal adults adjacent to the bottom was apparently not affected, but larvae were even sparser than in the bay of Fundy (see p. 288). Eggs of *Meganyctiphanes* and *Tautogolabrus* (M. P. Fish 1931) were at times particularly numerous, but surface temperatures apparently remained too low for successful incubation. Farther west in the relatively stable waters of Casco bay with low bottom and high surface temperatures, both adults and young thrive (euphausiid larvae amounted to 40.6% at sta. A in August 1932, table XIX). In the relatively homogeneous water of Passamaquoddy bay the scarcity of both boreal adults and larvae throughout the summers of 1931 and 1932 indicates conditions somewhat comparable with the bay of Fundy.

It therefore seems evident that although mechanical mixing does not in itself appear to be a limiting factor, as an agent in affecting temperature distribution

during the period that the water mass is subjected to solar heating, it marks the boundaries of biological barriers. Summer surface temperatures, as indicative of the degree of turbulence, can be considered to define directly areas most favourable for production of boreal species in the region, and indirectly and in a more general manner the quantitative distribution of the adult zooplankton population. The extent of mixing in different localities is shown in the following table.

TABLE XXVII. Maximum vertical range of temperature at representative stations

1932	Gulf of Maine				Bay of Fundy			
Station	26	29	31	32	5	8A	11A	36
April	3.3°C	0.9°C	1.6°C	0.4°C	0.5°C	0.3°C	0.7°C	1.2°C
May	5.3	3.6	1.8	0.8	0.7	0.2	0.3	3.3
June	10.7	4.9	5.0	0.9	1.0	1.6	0.3	3.6
August	13.7	10.3	10.4	1.5	2.5	3.6	4.1	6.0
September					2.2	0.5	0.8	2.2

The cold Nova Scotian current (Bigelow 1927, p. 832) may extend the boundaries of the unproductive zone (p. 311) for a time in the spring by retarding surface warming over a large part of the eastern basin during the period of vernal propagation. Its influence is temporary, however, and later, as previously described (p. 309), extensive propagation takes place in this area, particularly of species in which the numbers of larvae do not reach their seasonal peak in the first brood (*Pseudocalanus* and *Oithona*).

Unlike boreal zooplankton and fishes having pelagic eggs, benthonic invertebrates in all stages have a relatively wide thermal range and appear to suffer little from the results of turbulence. In fact larval pelecypods (*Mytilus* and mollusc DE, p. 227) were found in the largest numbers where most violent mechanical mixing occurs. (Rotifers too were concentrated in the same manner both in Frenchmans bay and the Fundy region (p. 244)).

Were it possible to assign a definite thermal range for the boreal group, or even individual ranges for each species, the problem of establishing definite areas as productive or non-productive would be simplified. This is not possible, however, either in the case of adults or developmental stages.

In adults the existence of physiological races with different thermal ranges is well recognized, and their presence in western Atlantic waters evident. The maximum temperature limit of boreal species like *Calanus* in the bay of Fundy is significantly lower than at Woods Hole. (This species has also been taken at the surface in the Florida straits in July (Field and Fish 1929, p. 2)). Therefore until the geographical ranges of the different races along the Atlantic coast have been determined, it will be difficult to correlate results from different regions. Although it has not been established we are assuming that, in each species, but one race exists in the gulf of Maine and bay of Fundy.

Within the gulf-Fundy region, however, developmental stages offer a further problem. In order to explain the varying degree of success in survival of eggs and larvae in different parts of the gulf and bay, it seems necessary to assume that the lethal temperature limits vary in different stages of development. It has been observed in both marine invertebrates and vertebrates (Vernon 1899, Huntsman and Sparks 1924, Runnström 1927, Bogorov 1932, etc.) that certain species in their earliest and adult stages tend to be more stenothermic than in intermediate stages. In Runnström's experiments *Cione* larvae survived normally at a temperature 10°C. higher than when hatched, and Vernon found that the lethal point in *Strongylocentrotus* was 11.8° higher than for eggs. This permits an immigrant stock entering in larval stages to survive in certain localities where successful breeding cannot take place.

The situation in the case of some true planktonic species appears to be different. Here observational data indicate that early and late stages are relatively eurythermic and intermediate larval stages more stenothermic. There is a fair percentage of survival of late copepodite stages of copepods entering the barren turbulent region, which mature and spawn. These eggs are fertilized and pass through varying intervals of incubation. Some hatch but the larvae soon disappear. Larvae surviving in more favourable areas appear to become increasingly stenothermic as development progresses. In the vernal crop, although eggs are hatched in temperatures of 7°C. or less in April, larvae (nauplii and early copepodites of copepods; calyptopis and furcilia stages of euphausiids) apparently do not survive at similar temperatures when transported into the turbulent area in May and June. In the case of *Meganyctiphanes norvegica* in 1932, calyptopis and furcilia stages were found restricted largely to the western area where surface temperatures at this time ranged from 10.5 to 15.9°C. Again in August early cyrtopian stages (9 to 11 mm.) were found for the most part restricted to the western area in surface temperatures ranging from 14 to 19.3°C., the greater number occurring where the temperature exceeded 15°C., although the surface temperature throughout the bay of Fundy (except in the Quoddy region) was 5 to 6° higher (12°) than that at which they hatched.

The development of boreal forms would thus appear to be closely attuned to normal vernal warming of the surface water, and most favourable conditions for survival occur in stable areas where each progressive stage (until maximum summer temperatures are reached) is subjected to an increasingly higher surface temperature. Approaching the adult stage the young appear to again become increasingly eurythermic, as indicated by a wide distribution of the more advanced members of the spring crop of *Meganyctiphanes* (12 to 18 mm.) in August, and the influx and apparent survival of members of the summer crop at similar stages in the bay in November and December.

Variable resistance in developmental stages was not as readily detectable in copepods, but in general conditions appear to be similar, as only those entering the turbulent area in copepodite stages survive. It is in these stages that the winter population of the bay of Fundy is recruited.

DISPERSAL

Dispersal of eggs and larvae, concentrated in the upper levels, corresponds closely with non-tidal circulation (Bigelow 1926, pp. 70-75 and 155; Fish 1936a, 1936b and c). Movements of both the western and eastern breeding stocks, when occurring in sufficient numbers, were found to be reasonably well indicated by monthly changes in the distribution of larvae in progressive stages of development.

Following vernal propagation in the western coastal area, larvae of the dominant species, *Calanus finmarchicus,* were found extending offshore and eastward around the outer margin of the gulf (Fish 1936a, fig. 6A). An appreciable part of these migrants or their progeny were found, on subsequent cruises, completing the circuit within the gulf or entering the bay of Fundy along the Nova Scotian coast as described on p. 205. Later, as some species become established in the eastern basin, summer broods (p. 312) are then supplemented by important contributions from this area, at which time the number of early stages entering the barren zone is greatly increased. These however, like locally produced larvae in the bay, soon disappear.

The dispersal of developmental stages was reflected in a general way in the distribution of late juveniles and adults, but the movements of the latter appear to be somewhat slower because, in descending during the day, they encounter a slower rate of subsurface drift. However, it is evident from the distribution of eggs and early larvae (Fish 1936b, figs. 6A and B; 1936c, fig. 6B) that a considerable number of adults subjected to low temperature and delayed maturation (eastern stock) are transported west of Mount Desert before spawning. In fact it is possible that the maintenance of the eastern stock is to a large extent dependent on these migrant adults reaching the proximity of favourable areas before spawning, as the vernal brood in May appears at a time when even the eastern basin appears unproductive (p. 312).

Since the various areas form sectors in a cyclonic system and are subjected to a continuous non-tidal drift, there arises the question of how the western area retains such a large concentration of zooplankton animals in all stages of development, and also how turbulent areas remain so consistently barren.

With regard to the former, during the propagation period it would be reasonable to suppose that eggs and larvae of the local crop would be transported seaward out of the region, and, with a relatively unproductive zone to the eastward available as a source of supply, the coastal zone would tend to be largely depleted of larvae. As this does not occur other factors must serve to counteract offshore dispersal of a substantial part of the stock. No conclusive explanation is afforded by the present data, but the distribution of larval stages of *Calanus finmarchicus* of the first western brood in a section off Casco bay on May 2, 1932, is suggestive. As one would expect, extending seaward from station 25A (fig. 2) progressively later stages were found along the course of the off-shore drift. In figure 45, nauplius stages I-II and III-IV are seen to be equally abundant at

station 25A. At station 24A (10 miles seaward) stages III-IV dominated, at station 23A (10 miles) stages V-VI, and at station 26 (20 miles) many were still in nauplius stage VI but these were far outnumbered by combined copepodite stages I and II. At this point there occurred an apparent reversal of course with

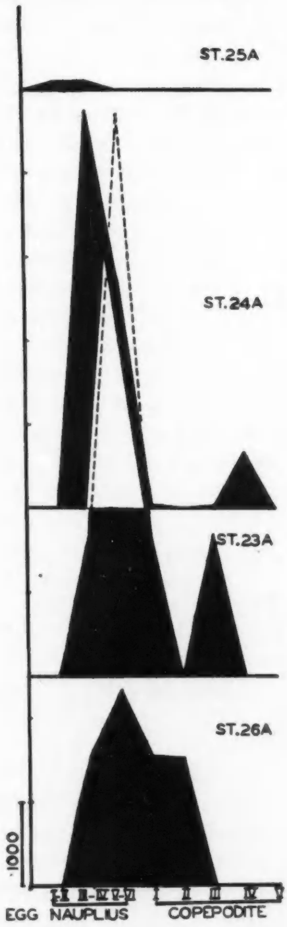


FIGURE 45. Distribution of *Calanus finmarchicus* larvae in different stages of development in a section off Casco bay in April, 1932. Oblique haul, 50 metres to surface; number per minute of towing a half-metre net.

a subsequent progression of copepodite stages in a shoreward direction, copepodite III dominating at station 23A, and copepodite IV at station 24A. Considering the almost complete absence of intermediate stages at stations 23A and 24A it would appear that, having reached the second copepodite stage in the region of

station 26, the larvae then retraced their steps. Such a procedure would be inconceivable at the surface, but, if a counter movement toward the coast takes place in lower levels, older stages descending to greater depths would tend to be carried with it. Our hydrographic data are insufficient to afford much assistance but they offer no negative evidence. If a compensating subsurface movement is found to occur it may prove of considerable importance in maintaining the stock in the western area.

The reason for the consistently small summer population in the turbulent areas is more obvious, for, added to unsuccessful local propagation, there is an effective physical barrier retarding the rate of interchange with the more productive neighbouring areas, comparable with that in the Quoddy passages (p. 302). As stated by Watson (1936, pp. 190-191) ". . . any area which contains homogeneous water, however this may be formed, will be conspicuously lacking in permanent residual currents." Thus contributions from outside waters must at best be acquired relatively slowly. Supplementing present plankton data there is the evidence afforded by drift bottles (pp. 209-213) and previous observations (Bigelow 1914a, p. 34, p. 130; 1926, p. 83). During the winter months, when the population is dominated by long lived copepodite stages of copepods (Fish 1936a, p. 137), volumes may gradually become more comparable with other areas, but following vernal augmentation these forms quickly die off, and as copepodites of subsequent broods are introduced, they mature and disappear so rapidly that no appreciable accumulation appears to take place, at least until the winter stock again becomes established.

NATURAL ECONOMY

The extreme seasonal fluctuations in the volume of both adult and larval zooplankton organisms must be of vital importance in the natural economy of the region. (The present method of numerical analysis does not show in true proportion the relative importance of euphausiids. Although usually far outnumbered by smaller species, they frequently form the bulk of the catch (p. 239). As described on page 219, plankton volumes are at a minimum in early spring (late February and early March) and rapidly increase to a peak in May-June following vernal propagation when the new crop approaches adult size (figs. 20 and 21). Almost all of the dominant boreal species begin spawning in late March or early April and all make contributions, but the quantitative fluctuations in the mass reflect to a large extent changes in the stock of the most important species, *Calanus finmarchicus* (Fish 1936a, p. 121). Accordingly, with the rapid depletion of the *Calanus* stock during the critical period of maturation (between the maximum of copepodite stages of the first brood in late May and the maximum of eggs of the second in June, (Fish 1936a, p. 136) there occurred the decline in total zooplankton volume indicated in figures 20 and 21.

Whether the longer lived (winter) parent stock of the first brood is more prolific, or whether the coincident increase in predatory enemies of the larvae is accountable for the continuous decline in volume after the May peak, is not known,

but the decline continued throughout the remainder of the summer in spite of subsequent broods with much larger parent stocks than were present in March. Assuming that the two years are comparable, the difference of 80 per cent (p. 216) in the September and April volumes represents the degree of unexpected winter depletion in the region.

The importance of larval stages of pelagic crustaceans cannot be too strongly emphasized, because of their value as food for larger invertebrates and vertebrate larvae. As has been pointed out in previous papers (Fish 1936b, p. 214; 1936c, p. 185), the relative numerical value of larvae of the various species is not necessarily the same as that of the adults. Based on the comparative abundance of individuals in developmental stages and the rate of depletion, *Pseudocalanus* and *Oithona* are at times of far greater importance to animals feeding on copepod larvae, than *Calanus*. Ogilvie (1927) also found *Pseudocalanus* and *Oithona* to be the most abundant food in the stomachs of post-larval herring from the Scottish coast.

Another factor of importance in the economy of the gulf and bay is the occurrence of the seasonal maxima of different dominant species at successively later periods during the summer. This results in an abundant supply of copepod larvae widespread in the region from April until September. Whereas *Calanus* reaches its peak in May (first brood), *Pseudocalanus* is most abundant in June (second brood), and *Oithona* (third brood) in August. Later in August *Centropages* appears and forms an important part of the larval stock in September. Why with all of these important boreal species, with the exception of *Centropages*, passing through a similar progression of generations, one should have the first brood of larvae dominant, another the second, and still another the third, is difficult to explain, but there results a rich source of food throughout the propagation period of summer spawning fishes.

TABLE XXVIII. Mean numbers of larval stages of dominant species of copepods in the total region in 1932. April-June: number per minute. August-September: number per cubic metre.

1932	Calanus finmarchicus	Pseudocalanus minutus	Oithona similis
April	2,007	7,126	1,112
May	7,024	11,484	5,918
June	2,156	21,303	8,919
August	977	5,639	34,852
September	41	3,506	3,262
Apr.-Sept. (Mean)	2,441	9,812	10,813

Very early pelagic larvae of *Ammodytes, Clupea, Gadus* and *Pholis* observed in the present investigation were found to be feeding almost exclusively on crustacean larvae. Unfortunately the numbers obtained were not sufficiently

large to be conclusive, but if they prove representative, a correlation may be found to exist between fluctuations in year classes of some of the spring and summer breeding fishes, and quantitative variations in their food. In the case of cod, the breeding season north of cape Ann (Bigelow and Welsh 1925, p. 422) coincides with vernal augmentation of *Calanus* and *Pseudocalanus*. Farther east on the Grand bank, young of the two groups were also observed together on June 5 to 17, 1924, by the senior author, and stomach contents of 17 early larval cod examined consisted entirely of *Calanus* nauplii. (Two specimens at station M5 (46° 48'N., 51° 45'W.) on June 13, and 15 specimens at station M8 (46° 44'N., 52° 25'W.) on June 17, 1924, in vertical hauls from 100 metres). It seems conceivable that if for some reason the seasons should not coincide and cod hatched before copepod propagation began or after development had reached copepodite stages, accessible food might be sufficient for only a small part of the usual stock. Although there is no actual proof that this ever occurs in the region, the possibility is suggested by the observed annual variation both in the size of copepod stocks (*Centropages*, pp. 236-237) and the time of spawning (*Acartia*, p. 294).

Larval crustaceans also frequently form an important source of food for adults of such ordinarily selective feeders as mackerel, as has often been noted. A number of this species in an open pool at Woods Hole in 1933 were observed by Mr. O. E. Sette to have two distinct types of feeding: (1) the selection of relatively large particles of food (chopped fish or mollusks); and (2) the indiscriminate straining of water for more minute organisms.

The regional distribution of food available for plankton feeders parallels closely relative productivity in different areas. It has been seen (pp. 219 to 227) that the supply in the gulf is much greater than that of the bay, the largest volumes occurring in the productive western and outer gulf during the early season and later expanding to include the eastern basin in midsummer. Within the bay of Fundy, which depends largely on immigration for its zooplankton supply, the largest volumes, most closely approximating those of the gulf, are found along the Nova Scotian shore in the entering drift.

According with previous records (Bigelow 1914a, pp. 34, 104 and 130; 1926, pp. 83-85) the supply, both in 1931 and 1932 (pp. 220 and 294) was consistently sparse in the non-productive coastal zone eastward from Mount Desert, with minimum amounts usually centred in and about the Quoddy area (figs. 41 and 42). Furthermore, as shown in figure 42, within Passamaquoddy bay the quantity of zooplankton throughout the year was generally even scantier than in Outer Quoddy waters (sta. 5). It would thus appear that so far as total abundance of this type of food is concerned the Quoddy area forms the least favourable of all observed localities in the entire region.

This point is of importance in the problem confronting the Commission because the possibility that the reported concentrations of sardine-sized herring in the Quoddy region are correlated with the zooplankton food supply has repeatedly been advanced (Graham 1936, pp. 122-125). For such a correlation there must

either be an abundance of food, or it must be particularly accessible. That correlation of herring and its food in Quoddy waters is not possible in terms of local production, or the local amount of food, has also been concluded by other recent observers (Battle, Huntsman et al. 1936, p. 427).

Again the possibility suggested by Huntsman (1934) that, although smaller in volume, the plankton distributed through the water mass in the mechanical mixing process is rendered more accessible to herring feeding in the upper levels during the daylight hours (Battle 1934) than a larger zooplankton population concentrated at or adjacent to the bottom, seems equally open to question in light of present data indicating that vertical stratification of even the smaller zooplankton organisms does not generally appear to be seriously affected over most of the western passage even during the periods of most violent turbulence. To other examples (pp. 302-304) showing the character of the mechanical mixing in this locality to be such that vertical movement is rather limited as compared with lateral eddy displacement, may be added the following: (1931) station 3, September 16, *Centropages typicus* 28.1 per cent at the surface, 7.8 per cent at 25 to 30 metres, and *Pseudocalanus minutus* 18.5 per cent at the surface, 30.7 per cent at 25 to 30 metres; station 4, September 15, *P. minutus* 8.1 per cent at the surface, 21.8 per cent at 25 metres. Vertical stratification of plankton is also implied in a recent statement on the feeding of herring by other observers, "The fact that they feed near or at the surface in the Quoddy passages during the day is not owing to there being more food near the surface, for the reverse is the fact . . ." (Battle, Huntsman, et al. 1936, p. 421).

It seems unlikely that euphausiids, the one form commonly observed swarming by day in the upper levels, could alone account for a sardine-sized herring concentration in the Quoddy region, for in addition to their apparent sporadic occurrence in appreciable numbers (p. 304), stomach analyses show no evidence that they are especially sought after as food. The food taken appears to be that most readily available in the locality at the time, although some variation with the size of the fish has been noted (Johnson 1933), the percentage of smaller plankton forms (*Pseudocalanus*) being somewhat greater in herring of small size (13 to 15 cm.). Thus in comparing 1931 summer net collections (table XIX) with stomach analyses in 1933 (Johnson 1933) it may be seen that dominant members of the population at that season, *Calanus, Pseudocalanus, Eurytemora, Temora* and *Acartia,* also, occurred most often in herring. Within Passamaquoddy bay (apparently before the *Acartia* maximum in 1933) the neritic copepods *Eurytemora* and *Temora* dominated in stomach samples, while in the passages the boreal species, *Calanus, Pseudocalanus* and *Meganyctiphanes,* formed almost the sole food. Throughout the whole Quoddy region Johnson found copepods the most common food. Similar results have been obtained in controlled feeding experiments. "Overnight, with the light kept on, the copepods all disappeared, but there was no indication that the fish had taken any of the Euphausiids introduced, which they cannot capture so readily." "Moreover, experiments in 1934 showed that

the herring will take dead *Meganyctiphanes* only when chopped in pieces." (Battle, Huntsman et al. 1936, pp. 410 and 412).

The whole question of accessibility of herring food in Quoddy waters and elsewhere in the region would appear dependent upon a determination of the depth at which the fish can and do feed. Precise data concerning the depth at which herring swim are lacking (Battle, Huntsman, et al. 1936, p. 421), but it is reasonable to assume that to feed they will seek the level of most abundant accessible food—and accessibility is dependent upon illumination sufficient to render the food visible enough for capture. Most fishes appear to depend largely on sight in locating and capturing food (Bigelow and Welsh 1924, pp. 416 and 451; Clarke 1936, p. 454).

In regard to depth of visibility in fishes, Grundfest (1932) determined the photosensitivity of the sunfish (*Lepomis*), and Clarke (1936) on this basis has calculated the maximum depths at which this species or others of similar vision could see in various types of water in the western Atlantic. Exact figures are not available for *Clupea,* but in view of its activity and method of feeding, it seems justifiable to assume that its vision is as keen if not keener than that of the relatively slow moving and bottom feeding freshwater sunfish (*Lepomis*). In the following table, prepared by Clarke, data are presented in support of his conclusion that throughout the gulf of Maine and elsewhere in coastal waters vision is possible for such fish from the surface to the bottom.

Table XXIX. Maximum depth for vision of fish (similar to Lepomis) in various types of water in the western Atlantic

Types of water	Depth of minimum illumination for vision of fish similar to Lepomis	Depth of water to the bottom
	metres	metres
Deep basin of gulf of Maine	230	165
Georges bank	180	60
Head harbour, bay of Fundy (sta. 5)	190	92
St. Croix river off Robbinston, Me., Passamaquoddy bay	26	26-29 approx.

Records for station 5 and St. Croix river based on observations of Reginald Sawyer.

In relatively shallow areas like the gulf of Maine and bay of Fundy where the depth of the water is considerably less than the depth of minimum illumination for vision of fish (similar to *Lepomis*), the duration of the period of visibility sufficiently clear for the capture of small prey must be proportionately increased (Clarke 1936, p. 454). Thus in the Outer Quoddy region at station 5, where the calculated depth of vision is more than twice the actual depth, feeding even to the bottom would be expected over a reasonably long period during the daylight hours.

If one assumes that Quoddy herring have vision as keen as that of sunfish,

the significance of vertical distribution of zooplankton in the present problem would appear questionable, as the entire water mass would in this case be within the range of visibility. Since this has not been established, however, it is of importance to note that following the onset of vernal augmentation and continuing through the summer of 1932, the maximum volume of zooplankton was at all times found above the 50 metre level (p. 231 and fig. 21), both in the bay of Fundy and gulf of Maine (table III). These records are for the most part based on hauls taken after sunrise and before sunset, in metre nets which allowed all but the more advanced developmental stages of Entomostraca to escape. Considering Clarke's calculations (table XXIX), zooplankton in the upper 50 metres would, during the daylight hours, almost certainly be expected to prove accessible to any fish dependent on keen vision for the capture of food. If this proves to be true, then with the much greater food resources of the offshore areas accessible, added importance is given to the suggestion (p. 318) that the Quoddy herring may not represent a concentration but merely more favourable conditions for fishing.

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